March 2004

ENGINEERING EVALUATION OF CITY OF SPRINGFIELD FLOOD HAZARD REDUCTION PROJECT BETWEEN HOLLAND AVENUE AND CAMPBELL AVENUE

Prepared for:
City of Springfield Missouri
Department of Public Works

Prepared by:
Wright Water Engineers, Inc. (WWE)
Denver, Colorado

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Engineering Evaluation of City of Springfield Flood Hazard Reduction Project Between Holland Avenue and Campbell Avenue

1.0 PURPOSE

The City of Springfield, Missouri Department of Public Works retained Wright Water Engineers, Inc. (WWE)[1] to evaluate the need for and feasibility of a proposed flood hazard reduction project on Fassnight Creek in the reach between Campbell Avenue (downstream) and Holland Avenue (upstream). This is referred to as the "study reach" in this report. The study reach is about 0.76 miles (3,385 feet) long, measured along the centerline of the stream channel. The project essentially consists of acquiring approximately 20 residences that are currently in the 100-year floodplain (some are also in the floodway, or "core" of the floodplain) in conjunction with the construction of additional open channel and culvert conveyance capacity. Drawing 1 provides a detailed map of the study reach, while Figure 1 shows the Fassnight Creek watershed. Figure 1 and Drawing 1 are at the back of the report.

This review was prompted by questions and concerns expressed by neighborhood residents about the proposed project and a desire from Public Works staff to obtain an independent assessment of the project. Representative questions that WWE was asked by the City of Springfield (City) to address include:

1. What is the level of flooding risk to the public in this reach of Fassnight Creek?

2. Is the City's proposal to purchase and relocate certain homes, followed by construction of improvements that will provide adequate conveyance capacity for the 100-year flood, reasonable, consistent with national floodplain management practice, and necessary?

[1] The primary WWE staff members who prepared this evaluation were Jonathan E. Jones, P.E. and Thomas Langan. Kenneth R. Wright, P.E., who founded WWE in 1961, served as reviewer for Messrs. Jones and Langan. WWE has extensive national experience with flood risk evaluation and reduction.

3. Are there alternative proposals which have not been evaluated to date that appear more feasible?

4. What is WWE's recommendation as to how the City should approach the project?

This report addresses these questions and others that are closely related, including many concerns and questions which were posed to WWE by community residents and property owners (see Section 9).

2.0 SUMMARY OF MAJOR FINDINGS

On the basis of many factors described herein, there is significant risk to public health, safety, and welfare due to Fassnight Creek flooding in the reach between Campbell Avenue and Holland Avenue. The City's proposal to acquire certain homes (on a voluntary basis and at fair market value), followed by construction of open channel and culvert improvements that will convey the 100-year flood, is prudent, consistent with national floodplain management policies, and necessary.

Based on suggestions from neighborhood residents, as well as our assessment of this situation, alternatives to the City's proposal were carefully evaluated. These alternatives were designed to enable the existing homes to remain in place. However, these alternatives fail to provide an acceptable level of flood hazard reduction and are otherwise not feasible.

Neighborhood property owners have raised many reasonable questions and concerns regarding the project. They have also provided valuable historical information. The most important theme that emerged from discussions with property owners can be stated as follows: *The flooding risk in the neighborhood is not as severe as portrayed by the City, and the proposed project is an over-reaction to the situation.* As stated by one of the homeowners: *the proposed cure is worse than the underlying disease.* WWE gave careful consideration to these concerns, which are described in detail in Section 9. In fact, our evaluation of alternatives which focused on the control of smaller, frequently occurring floods was in direct response to this concern. WWE's evaluation also included the specific alternative for reducing flood risk suggested by property owners in the study reach (see Section 7). However, as explained herein, this is not a situation where it is reasonable to address only small, frequently occurring storms, nor would the alternative suggested by the property owners adequately address the existing flood risk.

In the course of conducting this evaluation, many important policy questions related to flood hazard reduction arose. To assure that our understanding of these policy issues was correct, we interviewed 11 national experts (see Section 8).

WWE's overall recommendation is for the City to proceed with its preferred alternative (described in Section 7) as planned and proposed. We recommend an approach which emphasizes *voluntary* acquisition of flood-prone properties and a phased approach to construction of improvements. The City has repeatedly stated to property owners that this program is voluntary and that approach should continue. Logically, the first reach to address should be between the Bennett Street bridge crossing of Fassnight Creek and Campbell Avenue. The next reach would be between the Bennett Street bridge and Jefferson Avenue. Subsequent phases would address the remaining reach from Jefferson Avenue to Holland Avenue. Additional recommendations are provided in Section 11.

3.0 BASIS OF EVALUATION

To conduct this evaluation, WWE did the following:

- Interviewed Public Works Department staff.
- Interviewed neighborhood residents and property owners. Interviews were conducted both over the phone and in person (Jonathan E. Jones, P.E. of WWE met with about one dozen homeowners on October 21, 2003).

- Interviewed national floodplain experts on important policy questions.
- Interpreted topographic mapping, aerial photographs, the applicable 1991 Flood Insurance Rate Map (FIRM) and other documents of this kind.
- Field inspected the study reach of Fassnight Creek and the upstream watershed in October 2003.
- Reviewed and independently ran hydrologic and hydraulic computer models for Fassnight Creek in the study reach. These models were prepared by the City to generate peak flood flows for various return frequency storms, and to define the corresponding floodplains for these storms. We also worked with City staff to evaluate the feasibility of new alternatives.
- Reviewed and utilized information provided by neighborhood residents, primarily Messrs. David Dugan and Larry Barnett.
- Reviewed and utilized information provided by Public Works Department staff.
- Reviewed and utilized information from federal, state and local governments and other sources that address flooding, and relevant flood hazard literature.
- Conducted independent engineering analysis.
- Requested that City staff and Mathews Associates (MA) review a draft version of the report, to check it for factual accuracy and to assure that WWE was properly conveying City policy regarding flood risk reduction. WWE also requested that neighborhood property owners who have provided input to the City and/or WWE previously review a DRAFT version of the report for factual accuracy.

WWE sincerely appreciates the considerable amounts of information and assistance that were provided by both neighborhood residents/property owners and City staff.

4.0 NATURE OF STUDY AREA, INCLUDING FLOODING HISTORY AND FLOOD FLOW PROJECTIONS

4.1 Watershed Characteristics

The Fassnight Creek watershed is delineated on Figure 1. The watershed upstream from Campbell Avenue is approximately 3.17-square-miles-in size. The watershed is highly developed, with about 50% impervious area. Although the predominant land use is residential, there are also major commercial and industrial land uses including various shopping centers, Southwest Missouri State University (SMS) and St. John's Hospital, among others. The Fassnight Creek channel slopes from east to west at an average of about 0.5%. Runoff potential is high not only because of the large amount of impervious area but also because soils are generally clayey. Portions of the Fassnight Creek main channel and major tributaries are in buried conduits while other reaches are in open channels.

The watershed upstream from Campbell Avenue responds rapidly to rainfall events, and the creek is "flashy" in nature, with sharply rising and falling water levels, flows, and velocities. This point was emphasized by many property owners interviewed by WWE and demonstrated in a sequence of photographs taken by Mr. Dugan of a storm in June 2003.

4.2 Nature of Neighborhood Between Holland and Campbell Avenues

The residential community in the study reach is generally attractive and well maintained. Based on inspection of aerial photographs, the homes were typically constructed in the 1930s and 40s. Housing density is about 3-4 homes per acre. As discussed below, there are many long-time community residents, and WWE was fortunate to interview many of them. Photographs 1-6 provide representative views of the neighborhood.

4.3 Flood Flow Projections

Table 1 provides hydrologic data for the watershed at three locations of interest in the study reach. The flood flows provided in Table 1 were calculated by the City and, as discussed in Section 10, are reasonable based on WWE's review of the City's computer models and other analytical methods.

Table 1

Fassnight Creek Watershed Characteristics and Flood Flows at Key Locations (Flows in cubic feet per second [cfs][1])

Location	Upstream Drainage Area Size (square miles)	2-Year Peak Discharge[2]	5-Year Peak Discharge[2]	10-Year Peak Discharge[2]	100-Year Peak Discharge[2]
Holland Avenue	2.60	940	1,274	1,542	2,923
Bennett Street bridge	2.78	995	1,349	1,633	3,092
Campbell Avenue	3.17	1,142	1,552	1,880	3,474

1 One cfs is approximately 7.5 gallons per second (gps).
2 From City hydrologic model, discussed in Section 10. These flows are for the 3-hour duration storm for current conditions in the watershed. As discussed in Section 5.4.2, 3-hours is the appropriate storm duration for the Fassnight Creek drainage area tributary to the study reach.

Table 2 summarizes Fassnight Creek flood flow projections from previous studies.

Table 2

Summary of 100-Year and Other Flood Flow Estimates for Fassnight Creek at Various Locations

Source and Year	Location on Fassnight Creek (and Corresponding Drainage Area Size, if given)	Estimated 100-Year Peak Discharge	Other Information
U.S. Army Corps of Engineers (USACE), 1968	Fort Avenue (3.4 square miles)	3,500 cfs	---
Federal Insurance Administration and USACE (inter-agency agreement), 1973	Fort Avenue (3.4 square miles)	3,000 cfs	25-year floodwater surface elevation 0.5 feet lower than 100-year flood elevation. 200-year flood elevation 0.62 feet above 100-year flood elevation.
1990 Kramer Chen Mayo (KCM) Fassnight Master Plan Study	Campbell Avenue (3.17 square miles)	1,240 cfs	KCM study provides a 2-year peak discharge of 1,010 cfs and 1,150 cfs for the 5-year storm. Other flows are provided in the report.
Federal Emergency Management Agency (FEMA), 1991 (FEMA 1991a)	Study reach from Holland Avenue to Campbell Avenue	Approximately 3,500 cfs[1]	Flood elevation data also provided for 10-year, 50-year and 500-year floods
USACE, 1995	Campbell Avenue (3.17 square miles)	3,744 cfs	---
Wilson Consulting Engineers, 2001	Campbell Avenue (3.17 square miles)	5,534 cfs	---
City of Springfield, 2003	Campbell Avenue (3.17 square miles)	3,474 cfs	See Table 1, above

[1] The applicable *Flood Insurance Study* was prepared by FEMA on October 16, 1991. Although this report does not specify 100-year flow rates for the study reach, the 100-year flood elevations provided in the report are consistent with those from the USACE in 1973. This provides the basis for the 3,500 cfs rough estimate given in Table 2.

The City's flood flows in Table 1 are consistent with the Table 2 values. WWE's analysis indicates that the KCM flows are too low, and the Wilson Consulting Engineers flow is too high.

Another useful check on the Table 1 values is the historic flood observations provided by long-time neighborhood residents (some people have lived in the study reach for approximately 50 years). Major floods were described in 1951, 1993, and 2000, with regular episodes of street, alley and lawn flooding, inundation of the Bennett Street bridge and basement or crawlspace flooding. For example, interviews indicate that the Bennett Street bridge overtops a few times per year in a typical year, by roughly ½ to 1 foot of water, for short durations of roughly ½ hour.

All of these observations tend to support the Table 1 flow estimates, and they provide the basis for our evaluation.

4.4 Nature of Fassnight Creek Channel in Study Reach and of the Flooding Problem

Most of the development in the study area occurred in the 1930s–40s, and it was common at that time (not only in Springfield, but nationally) to not reserve sufficient space for the conveyance of flood flows. At that time, to the extent that drainage design occurred, there was rarely provision of an adequate, safe pathway for flows through urbanized areas. Typically, natural drainage channels were placed in pipes or narrowed through fill placement, and there was little recognition of the space that floodwaters would occupy (i.e., the floodplain). Unfortunately, this is the case for the Fassnight Channel from Holland Avenue to Campbell Avenue. The channel closed culvert is not large enough to convey flood flows. As a result, flows spill out of the channel culvert and move through the neighborhood, via streets, alleys and yards, while inundating crawl spaces and basements (first floor flooding has not been experienced by the people we interviewed, although 1993 and 2000 flood levels were nearly at first floor levels in many homes).

Immediately upstream from Holland Avenue, Fassnight Creek consists of an open channel (see Photographs 7 and 8). On the east side of Holland Avenue, Fassnight Creek transitions from an open channel into two 12-feet-wide by 5-feet-high side-by-side concrete box culverts (see Photograph 9). As shown on Drawing 1, these box culverts continue downstream to the west side of Jefferson Avenue, a distance of approximately 1,400 feet. On the west side of Jefferson Avenue, the box culverts end (Photograph 10) and an open channel section continues to the Bennett Street bridge. Photographs 11-15 show the open channel between Jefferson Avenue and the Bennett Street bridge, while Photographs 16-19 provide various views of the Bennett Street bridge, which consists of a two-cell 10-feet-by-2.5-feet box culvert. From the Bennett Street bridge downstream to Campbell Avenue, Fassnight Creek is an open channel with a mature riparian corridor and large trees growing on the channel banks (see Photographs 20-22 for representative views).

From the Bennett Street bridge upstream to Holland Avenue, the conveyance capacity of Fassnight Creek in its current condition is substantially smaller than not only the 100-year flood, but much smaller (and more frequently occurring) floods, as well. Hydraulic modeling conducted by the City (and checked by WWE) indicates that the maximum capacity of the two 12-feet-by-5-feet box culverts at overtopping is about 1,060 cfs (assuming no debris blockage), which is roughly equivalent to about the 5-year peak discharge at Holland Avenue. (It is also noteworthy that 1,060 cfs is about one-third of the 100-year flood at Holland Avenue.) Consequently, in all floods greater than or equal to approximately the 5-year event, the capacity of the existing box culverts will be exceeded, and that portion of the flow not carried by the culverts will move through the neighborhood. The conveyance capacity of the open channel between Jefferson Avenue and the Bennett Street bridge is actually less than that of the two upstream box culverts. This is due to a combination of factors including limited space, inadequate maintenance, the channel is privately owned and the City does not have access to it, collapsing railroad tie walls, a sharp bend, backwater from the Bennett Street bridge and, in general, a channel reach that is not efficient hydraulically. This reach of channel, in its current condition, has capacity for roughly the 2-year flood flows.

The Bennett Street bridge is grossly undersized, which is why it is inundated a few times per year on average, based on interviews with community residents and City staff. As discussed in Sections 5, 8 and 11, this creates an unsafe situation for pedestrians and motorists and is a matter that should be urgently addressed by the City. Downstream from the Bennett Street bridge, the floodplain widens substantially (see Drawing 1). As noted by neighborhood residents, there is some debris in the channel bottom downstream from Bennett Street, which should be removed to minimally increase conveyance capacity (see Photographs 20-22). Some of this channel is privately owned, which will influence the feasibility and nature of maintenance activities. Currently, it would be necessary for maintenance to be performed by the property owners.

In light of the limited conveyance capacity described above, it is not surprising that the 100-year floodplain is extensive, as shown on Drawing 1. Drawing 1 depicts both the FEMA 100-year floodplain and floodway boundaries (from Jefferson Avenue downstream) and the 100-year floodplain boundary based on the City's hydrologic and hydraulic modeling, from Jefferson Avenue upstream. Drawing 1 demonstrates that there are 76 homes, two churches and one business in the 100-year floodplain in the study reach (Holland to Campbell Avenue), and 28 homes, one church and one business in the floodway in this reach.

To summarize, between the Bennett Street bridge and Holland Avenue, the conveyance capacity of the existing system ranges from less than the 2-year storm to approximately the 5-year storm. In storms greater than this range (2- to 5-year), flood flows leave the dedicated conveyances (box culverts and open channel) and flow through the neighborhood, in streets, alleys, and yards.

5.0 ASSESSMENT OF FLOOD RISK

This section summarizes WWE's assessment of flood risk in the study reach. Flood risk is a function of many factors including, as examples: frequency, magnitude, and duration of flooding; number of structures in the floodplain and floodway; amount of property damage caused by various floods; nature and degree of flood hazard; impairment of street traffic flow and of emergency vehicle access; frequency and magnitude of bridge overtopping; nature of land use in affected neighborhoods and immediately adjoining areas; flood history; and others. These factors are discussed, as follows.

5.1 Flood History

Flooding history is an extremely important factor regarding risk assessment. It is well known that the relevant reach of Fassnight Creek has experienced significant floods frequently over the past 50 years. For example, based on interviews with City staff, documents reviewed, and interviews with property owners, major floods have occurred in 1951, 1993, and 2000. Three large events in 50 years represent a significant flood risk. Accounts vary as to which of these three floods (1951, 1993 and 2000) produced the largest peak discharges through the study reach. Mr. Wilbur Teal (439 W. Stanford) stated that the 1951 flood was the worst event. Mr. Warren Rankin (251 E. Bennett) became a resident of Springfield in 1952 and bought his current home (on Bennett Street immediately adjacent to the Bennett Street bridge across Fassnight Creek) in 1954. Mr. Rankin, who practiced civil engineering throughout his career and who is knowledgeable on drainage and flood control issues, stated that the 1993 flood produced the highest flood level at his home. Photographs 23 and 24 indicate Mr. Rankin pointing to the maximum historic flood depths at his home, while Photograph 25 shows Mr. Rankin's house in relation to the Bennett Street bridge. Data collected by City staff indicate that the July 12, 2000 flood (which occurred during the night) produced the highest flood levels on Fassnight Creek in the study reach. City staff surveyed high water marks at a number of locations in the study reach shortly after the July 12, 2000 flood. In any case, it is clear that the relevant neighborhoods are subject to periodic large flood flows.

There have also been numerous smaller floods that exceeded the capacity of the stream channel and Bennett Street bridge, and which caused flows to move through yards, streets, and alleys. Our interviews with long-time residents in the channel reach between Jefferson Avenue and the Bennett Street bridge indicate that typically every one to two years (and in some years, more than once), flood flows exceed the current channel capacity. Interviews also indicate that the Bennett Street bridge typically overtops a few times per year in an average year. The frequency of basement or crawlspace flooding is reportedly about once every 2-5 years. Some of this flooding is caused by sanitary sewer back-ups (in fact, as presented in Section 9, some property owners have stated that sewer backups are the primary source of their flooding). These facts indicate that there is risk associated with small, frequently occurring storms in addition to larger, less frequent storms.

5.2 Prior Flood Studies

As summarized in Table 2, many studies have calculated large 100-year flood flows on Fassnight Creek, including analyses by the USACE and FEMA. In 1990-91, the City commissioned a comprehensive master plan study of Fassnight Creek, which was conducted by KCM of Seattle, Washington. This study noted numerous flooding problems along Fassnight Creek and characterized the reach between Holland Avenue and the Bennett Street bridge as one of the most significant problems in the entire watershed (FEMA 1991a). The FIRM, published by FEMA in 1991, delineates a substantial floodplain from Jefferson Avenue downstream (FEMA 1991b). FEMA did not delineate the floodplain upstream from Jefferson Avenue. As discussed in Section 8, this is counter to FEMA's standard policy of delineating floodplains up to the location where a watershed is smaller than one-square-mile in size, or where the floodplain is less than 200 feet wide (FEMA 1999).

5.3 Rainfall-Runoff Data

Statistically derived data regarding rainfall intensities are important for establishing flood risks. Table 3 summarizes rainfall return frequency data for Springfield, based on long-term precipitation data gathered by the National Weather Service and statistically analyzed by the Midwestern Climate Center.

Table 3

City of Springfield Rainfall—Return Frequency Data for Fassnight Creek at Various Locations (3-hour storm duration)

Return Frequency Storm	Precipitation (inches)[1,2]
2-year	2.42
5-year	3.07
10-year	3.56
25-year	4.20
50-year	4.71
100-year	5.24

[1] Based on 3-hour duration storm, which is appropriate for the relevant portion of the Fassnight Creek watershed.
[2] Illinois State Water Survey Bulletin 71.

The values in Table 3 were input into the Fassnight Creek hydrologic model developed by the City (discussed in Section 10), with the resulting flood discharges at Holland Avenue, the Bennett Street bridge, and Campbell Avenue provided in Table 1. The flood flows in Table 1 demonstrate the magnitude of flood events through the study reach, for both frequent and infrequent rainfalls.

5.4 Flooding Depths and Velocities, and Significance of July 12, 2000 Flood

5.4.1 Flood Depths and Velocities

Flood depths and velocities are important for assessing risks. For example, the U.S. Geological Survey (USGS) has used a rule known as the "Product of 4" to define the risk of flowing water to people. Specifically, when the product of (flood depth) x (velocity) is greater than or equal to 4, a person is at risk. For example, water 1 foot deep, moving at 4 feet per second (fps) would pose a risk, whereas water 4 feet deep moving at 1 foot per second would also pose a risk. As another example, the City of Henderson, Nevada specifies that if roadway culverts are designed to convey less than the full 100-year flood before the road overtops, the product of (depth) x (velocity) for the overflow must be less than 3. Many "rules-of-thumb" of this kind are used around the United States.

The City prepared a hydraulic model for the reach between Holland Avenue and Campbell Avenue using the well-accepted model, HEC-RAS. For any given peak flow rate, this model will calculate the floodplain width, flood depths, and flood velocities at many locations (based on defined cross-sections within the model). The City ran this model for the 2-, 5-, 10-, 25-, 50-, and 100-year floods on Fassnight Creek. Inspection of model output indicates that hazardous combinations of flood depths and velocities exist at multiple locations between Campbell Avenue and Holland Avenue for both frequent and infrequent floods. This observation does not hold for all locations within the 100-year floodplain, but only for certain locations. For example, floodwaters moving from east to west along Bennett Street have relatively high velocities and pose more of a hazard than other locations. This observation was confirmed by inspection of videotape taken by Mr. Greg Davison, who resides on Bennett Street near the Bennett Street bridge crossing of the creek. Mr. Davison videotaped two floods in July 2000 from his front porch. In this video, water levels on a chain link fence were evident; Photograph 26 shows this chain link fence, located on the east side of Mr. Davison's yard. Photograph 26 was taken from Mr. Davison's living room window. The City surveyed the high water mark on this chain link fence following the July 12, 2000 flood, along with other locations in the study reach.

5.4.2 Significance of July 12, 2000 Flood

An aspect of flood depth that has generated much discussion within the neighborhood is that (according to a number of the property owners we interviewed) the 100-year flood does not produce first floor flooding, but only flooding of basements and crawlspaces. The basis for this assertion is that City staff apparently told property owners in the study reach that the July 12, 2000 storm was the "100-year flood." During this event, although many homes in the study reach experienced basement and crawlspace flooding, were surrounded by water, and had floodwater very close to first flood levels, with the exception of Mr. Greg Davison's residence (where one room had wet carpet) there are no other known cases where first floor flooding occurred. WWE independently evaluated the available precipitation and flow data for the July

12, 2000 flood and offers the following observations regarding the statement that this event was the 100-year flood:

1. The City's conclusion that the July 12, 2000 flood had a return frequency of 100-years was reasonable for a *6-hour* rainfall duration. However, when determining flood risks, it is important to evaluate the rainfall duration which maximizes peak flows for the drainage area in question. For example, the appropriate storm duration to use for a 100-acre drainage area might be 1-hour, or less, while the appropriate storm duration to use for a 50-square-mile drainage area might be 12-hours, or longer. In the case of the Fassnight Creek watershed in the study reach, the appropriate rainfall duration for defining flood risks is *not* 6-hours (duration of the July 12, 2000 rainfall), but *3-hours*. If the 100-year, 3-hour duration storm had occurred on July 12, 2000 rather than the 100-year, 6-hour duration storm, the peak flow would have been larger, and flood depths would have been higher.

   Using the City's hydrologic and hydraulic models, described in Section 10 of this report, WWE has contrasted flood flows and depths for the 100-year, 6-hour and 100-year, 3-hour duration storms. At Holland Avenue, the 100-year, 6-hour peak flow is 2,124 cfs, whereas the 100-year, 3-hour peak flow is 2,923 cfs, an increase of 38%. At the Bennett Street bridge, the 100-year, 6-hour duration peak flow is 2,256 cfs, whereas the 100-year, 3-hour peak flow is 3,092 cfs, an increase of about 37%. If these larger flood flows had occurred on July 12, 2000, flood depths would have been substantially larger than they were. WWE's analysis indicates that in the reach between Jefferson Avenue and the Bennett Street bridge, flood depths for the 100-year, 3-hour duration storm are about 0.6 feet *higher* than flood depths for the 100-year, 6-hour storm. In the reach between Holland Avenue and Jefferson Avenue, the 100-year, 3-hour flood depths are about 0.75 feet higher.

The bottom line is that when the most technically correct and appropriate 100-year flood storm duration is used, flood depths in the study reach are roughly 0.6 to 0.75 feet higher than were observed during the July 12, 2000 flood; such depths would have been above first floor elevations in many of the residences.

2. Another factor which needs to be accounted for when assessing future flood risk in the study reach is that, according to the City's hydrologic modeling, when the Fassnight watershed is fully developed, flood flows will be modestly higher than they are currently. For example, at Holland Avenue, the 100-year, 3-hour peak flow will increase from 2,923 cfs (as shown in Table 1) to 3,025 cfs, an increase of about 3.5%. This would translate into a small increase in the 100-year floodwater surface elevation.

3. As discussed in Section 10, the City calibrated its hydraulic (flood elevation) model, HEC-RAS, to the July 12, 2000 flood. The City's selection of certain friction loss parameters resulted in over-estimating the magnitude of this flood.

In summary, for the three reasons given above, the City has overstated the magnitude of the July 12, 2000 flood. The event, although severe, was not a "true" 100-year flood. If such a flood were to occur, there would be first floor flooding in the study reach. In addition, as described in Section 8, according to interviews that we conducted, there is no differentiation between first floor flooding and basement or crawlspace flooding from the standpoint of evaluating flood hazards.

5.5 Bridge Overtopping and Emergency Access

The bridge at Bennett Street is particularly problematic from a risk standpoint. Interviews indicate that this bridge overtops by roughly ½ to 1 foot of water a few times per year in a typical year. Table 4 summarizes overtopping depths at the bridge, for various storms based on calculations by the City. Note that Table 4 assumes that there is no debris blockage. Debris, such as tree limbs, could lodge against the upstream side of the bridge during floods, and this would cause the flood depths in Table 4 to increase.

Table 4

Depth of Floodwater over Bennett Street Bridge Under Current Conditions Based on Calculations by City[1]

Storm Event	Existing Conditions, Approximate Depth of Water over Bennett Street (ft)
1-year	1.2
2-year	1.4
25-year	2.1
100-year	2.6

1 Assumes no debris blockage at bridge. Any debris at bridge would cause overtopping depths to increase.

Various design standards and engineering references that we have reviewed, as well as interviews with national experts, indicate that flooding of this magnitude and frequency at a roadway bridge is unacceptable, particularly one that carries as much traffic as the Bennett Street bridge. Of particular concern is the proximity of Parkview High School, approximately 0.6 miles west of the bridge. When Jonathan Jones of WWE conducted a field investigation on October 21, 2003, he noted high school students driving across the Bennett Street bridge and observed a significant amount of traffic on Bennett Street. To provide one example of the incompatibility of the current situation with national standards, consider the following guidance from the 1992 reference, *American Society of Civil Engineers and Water Environment Federation Manual of Practice for the Design and Construction of Urban Stormwater Management Systems* (Urban Water Resources Research Council [UWRRC] 1992).

Street Classification	Minor Design Runoff	Major Design Runoff
Local	6-inch depth at gutter or in cross pans	18 inches of depth above gutter flow line
Collector	Where cross pans are allowed, depth of flow shall not exceed 6 inches	18 inches of depth above gutter flow line
Arterial	None	6 inches or less over crown
Freeway	None	6 inches or less over crown

Notes: “Minor” refers to 2-5 year storm. “Major” refers to 100-year storm. Bennett Street in this location would be classified as a Collector street, with an average daily traffic (ADT) of 1,800 vehicles/day.

Emergency vehicle access to many of the homes between Holland Avenue and Campbell Avenue would be problematic during flood events. As described above, there are dangerous combinations of depths and velocities at multiple locations. Again, many national standards documents and engineering references stress the need for providing emergency vehicle access to as many buildings as feasible during flooding conditions.

5.6 Flood Duration

Another factor related to risk is the duration of flooding—that is, how long do flood levels remain elevated? Homeowner interviews have indicated that Fassnight Creek in the study reach is “flashy”; that is, flood depths rapidly rise and fall during most storm events. Hydrologic computer modeling by the City confirms this observation, for smaller, frequent events. This is both good and bad; good in the sense that the flood does not last for long, bad in the sense that there is little advance warning. Larger events (2-year flood and larger) have longer durations, based on the modeling described in Section 10. The durations of the 2-year through 5-year storms and larger are definitely a concern for public safety.

5.7 Number of Structures in Floodplain

One of the most basic metrics used to evaluate flood risk is the number of structures that are located within the 100-year floodplain and 100-year floodway (the floodway can be thought of as the "core" of the floodplain, where the level of risk is highest) on a unit, length, or area basis. For unknown reasons, FEMA failed to extend the FIRM mapping on Fassnight Creek upstream as far as it normally does (to the point where the watershed is less than 1-square-mile in size). This point of demarcation in the Fassnight Creek watershed would be approximately National Avenue. The City delineated the 100-year floodplain and floodway for the reach between Holland Avenue and Campbell Avenue, based on the 100-year flood flows provided in Table 1. The resulting floodplain and floodway boundaries are provided on Drawing 1.

City staff informed WWE that on a unit area and unit length basis, Fassnight Creek between Holland Avenue and the Bennett Street bridge crossing has one of the highest concentrations of structures in the 100-year floodplain and floodway in the City. Drawing 1 shows that there are 76 homes, two churches and one business in the study reach 100-year floodplain, and that 28 homes, one church and one business are in the floodway. The City and MA also found that Bennett Street is impassible during even minor rainfall events, as shown in Table 4.

5.8 Significance of Underground Pipes, Limit of Floodplain Map and Number of Complaint Calls

Two factors which increase flood risks in the study area are the presence of the large underground box culverts and the lack of a formal regulatory floodplain/floodway upstream from Jefferson Avenue. The buried culverts likely provide a false sense of security to some local residents; moreover, we anticipate that some residents do not even know that these culverts exist and that there is a significant drainageway passing through this neighborhood. Another problem with piped conveyances vs. open channels is that they are more subject to debris blocking. Safety is generally enhanced in an open channel, as well.

The lack of a defined regulatory floodway and floodplain upstream from Jefferson Avenue likely provides a false sense of security for some unsuspecting property owners. It is probable that there have been property transactions in the reach between Jefferson Avenue and Holland Avenue where both seller and purchaser did not know that the property in question was located in an area that would be flooded by the 100-year flood (and in many cases, in smaller floods as well).

Most municipal public works departments, including Springfield's, maintain records of complaints regarding public infrastructure, including drainage systems. City records indicate that this reach of Fassnight Creek has, over time, received numerous complaint calls. For example, there were 15 complaints from property owners in the study reach following the July 12, 2000 flood.

5.9 Channel Between Jefferson and Bennett Street Bridge

The open channel in the backyards of the residences on the south side of Bennett Street between the bridge and Jefferson Avenue poses unusual safety hazards. The channel comes precariously close to the homes (see Photographs 11-15). Channel side slopes are nearly vertical in places. The side slopes are collapsing into the channel. There is inadequate channel stability protection. Flow velocities are high. During certain flows, the sharp bend in the channel could create a hydraulic jump (rapid increase in flood depth). For all of these reasons, WWE is very concerned about public safety in this reach of the channel. In addition, should the channel widen laterally, the structural integrity of one or more of the homes could be compromised.

5.10 Comparison to South Creek Conveyance Capacity and to Upstream Fassnight Channel Capacity

The City has put the conveyance capacity of the two existing 12-feet-wide by 5-feet-high culverts (between Holland Avenue and Jefferson Avenue) into context by comparing them against box culverts on South Creek. Where South Creek passes beneath Jefferson Avenue, there are five box culverts with dimensions 15 feet wide by 6 feet high. These culverts serve an urbanized watershed that is 1.8 square miles in size. By contrast, on Fassnight Creek between Holland Avenue and Jefferson Avenue, there are two 12 feet by 5 feet box culverts serving an urbanized watershed that is about 2.6 square miles in size. The South Creek box culverts were designed in the early 1990s to convey the 100-year flood. The Fassnight Creek box culverts, constructed in 1935, have adequate capacity for about the 5-year flood.

Another useful comparison is to contrast the large channel capacity of Fassnight Creek immediately upstream from Holland (see Photographs 7 and 8) vs. downstream from Holland (Photograph 9), where the conveyance is in the form of a box culvert.

5.11 Sanitary Sewer Backups

Due to infiltration and inflow into sanitary sewers during runoff events, the sanitary sewer system in the affected neighborhood has periodically surcharged and caused basement flooding. This is common with older sewer systems throughout the U.S. The City of Springfield has an aggressive program to reduce infiltration and inflow, which commits approximately $18M to rehabilitate the public sewer system. The City has completed approximately 40% of the recommended public sewer rehabilitation in the Fassnight Creek watershed. Even if the problem of sewer surcharging could be eliminated in the study reach, the risk of surface flooding would not change. In addition, studies indicate that approximately 50% of infiltration & inflow is from the private sewer system, which is under the control of the individual property owners.

5.12 Contribution to Nuisance Conditions in Basements and Crawlspaces

The frequent introduction of floodwater into basements and crawlspaces is problematic from the standpoint of nuisance conditions such as odor, mold, mildew, need for cleaning, etc. The problem of mold and mildew is currently receiving substantial attention in the media.

5.13 Summary of Flood Risk in Study Reach

For the many reasons described above, WWE has concluded that flood risks along Fassnight Creek in the reach between Holland Avenue and Campbell Avenue are high, and represent a significant threat to public health, safety and welfare.

6.0 OVERVIEW OF CITY OF SPRINGFIELD FLOODPLAIN ACQUISITION PROGRAM

Following the major flood of 1993 in Springfield, the Citizens Storm Water Committee (CSWC) recommended that the City and Greene County adopt proactive stormwater management policies to minimize future flooding by acquiring flood-prone properties and structures within designated floodplain and sinkhole areas. The CSWC recognized that floodwaters adversely impact neighborhoods, both financially and personally, and that the flooding cycle had to be broken. The CSWC identified the following community benefits from acquiring designated floodplains:

- Protects floodways from future development
- Reduces flood damage to existing properties
- Provides opportunity to increase conveyance system capacity
- Improves water quality by providing:
  - Bank stabilization
  - Open and green space
  - Routine maintenance
- Increases recreational and quality of life opportunities for the community

On this basis, both the City of Springfield and Greene County have adopted floodplain acquisition programs, and have purchased properties subject to flood risk. Springfield was the first municipality in Missouri to adopt a floodplain acquisition program (in 1993). The City acquired 17 homes in the Ferguson sinkhole area in 1994, and the County acquired multiple homes in the Shadowood area (Ward Branch) in 2001. The City has also acquired approximately 100 high priority structures since that time, all of which were in flood-prone areas. The July 12, 2000 storm demonstrated the benefits of the acquisition program within the

Ferguson sinkhole area. This neighborhood would have sustained significant damages and possibly loss of life given the rate at which this sinkhole filled with stormwater (in less than five hours).

Hundreds of American cities have voluntary floodplain acquisition programs. This practice is strongly encouraged by FEMA, state agencies, and engineering references. A leading example near Springfield is the City of Tulsa, Oklahoma, which has purchased over 1,000 flood-prone properties. This is one reason why Tulsa carries the highest (best) flood preparedness status from FEMA of any city currently participating in the National Flood Insurance Program.

Representatives of the City of Tulsa provided WWE with considerable background information on their flood hazard reduction program, including a May 1994 publication entitled, *From Rooftop to River, Tulsa's Approach to Floodplain and Stormwater Management*. Representative statements from the "Policy Framework" section of this document are as follows:

- *Floodplain and stormwater management is a matter of time and space allocation. Water requires space and must be stored and conveyed, in either appropriate or inappropriate places.*

- *Floodplains are natural storage and conveyance facilities, and all stormwater management efforts should be directed toward helping them serve that function.*

- *Acquisition and relocation should be used to reduce, over time, the occupancy and value of exposed property in flood hazard areas.*

- *Public park, recreation and open space use of the floodplain is the best policy (*this statement is under the sub-heading "Preventive Policies").

Floodplain acquisition programs are popular with elected officials because in the long run, they typically save public monies; promote public health, safety, and welfare; and break the cycle of repeated flooding. An excellent example of this is a bill that is now in the U.S. House of Representatives, HR 253. HR 253, approved in July by the House Financial Services Committee, is designed to put an end to repetitive federal flood insurance claims by authorizing a five-year program of aid to cover 75% of the costs of buying out property owners in flood-prone areas or helping them elevate, relocate, or otherwise flood-proof their homes and businesses. This provision provides the positive incentive. The negative incentive is also demonstrated by the bill's title: *Two Floods and You Are Out of the Taxpayers' Pocket Act of 2003.*

Acquisition of flood-prone properties in Springfield is prioritized based on the following criteria:

- Proximity to sinkholes (because protection through system improvements is often not feasible or cost-effective)
- Probability of recurring flooding
- History of flood damage
- Properties covered by flood insurance to maximize limited funding and to minimize future expenditures

When construction of a stormwater improvement project is not cost-effective or it is not practical to provide flood protection, and when a property meets the above guidelines, owner(s) are contacted to determine their interest in the voluntary acquisition program. If the property owner indicates an interest, the City retains a certified real estate appraiser to establish the market value of a property. The property is appraised in a pre-flood condition; however, the appraisal does take into account location of property, i.e., within a designated floodplain or floodway. The City then makes an offer to acquire property based upon the certified real estate appraisal less any flood insurance proceeds. This voluntary program offers considerable flexibility to the property owners in terms of scheduling a time for closing on the acquisition. In addition, the City pays for customary closing costs with the exception of the pro-rated real estate taxes.

Floodplain acquisition is only one of many steps that the City presently takes to reduce flood risks; other mitigation measures include, for example:

- Major drainage master planning
- Updating/correcting floodplain maps
- Channel construction
- Retention/detention pond construction
- Channel stabilization
- Active participation in many other facets of the National Flood Insurance Program, including the City's current status with FEMA of a cooperative technical partner
- Community education

7.0 POTENTIAL FLOOD RISK REDUCTION ALTERNATIVES EVALUATED BY CITY OF SPRINGFIELD AND WWE

7.1 Background and Initial Alternatives Evaluated

To address the flood risks described in Section 5, the City Public Works Department, along with MA, initially evaluated three alternatives, all of which were designed to meet the established objective of protecting properties in the study reach from the 100-year flood. An open house public meeting with the neighborhood was held on May 22, 2003 to discuss preliminary findings for the three design alternatives. (Section 9 of this report summarizes key property owner questions and concerns).

One of the three alternatives studied added the maximum feasible size box culvert under Bennett Street to increase flow capacity. Detailed analysis demonstrated that although this approach would increase the below-ground conveyance capacity from the current level of about a 5-year storm to roughly a 10-year storm, this was an inadequate solution for the 100-year flood, as it would lower the flood elevation by less than 0.5 feet in areas where water depths were as much as 3 feet. The capital cost of this alternative was about $4 million.

The other two alternatives included an open, grassed channel to carry floodwater. The channel would need to be approximately 100 feet wide and would be similar in appearance to the channel constructed between the Erie and Ferguson sinkholes in southwest Springfield. One of the open channel alternatives included the removal of the existing 12 feet by 5 feet culverts while the other keeps the existing culverts and uses a slightly narrower channel. Homes that front on the south side of Bennett from Kimbrough to the Bennett Street bridge would need to be removed by either moving or demolition to provide sufficient space to construct the necessary channel. As many as five houses north of Bennett and west of Jefferson may be too low to be protected and therefore, may need to be removed, even with construction of improvements.

Other elements common to all three of these alternatives include:

- The construction of a three-cell box culvert between Holland Avenue and Kimbrough Avenue. The dimensions of each cell (opening) would be 12 feet by 5 feet. (This new culvert would add to the capacity of the current box culverts in this reach, which would remain in place.)

- Closing Roanoke Avenue at Bennett Street to permit construction of the open channel on the south side of Bennett Street.

- The construction of a five-cell box culvert at Jefferson Avenue, with each cell dimension of 12 feet by 5 feet to match the capacity from Holland to Kimbrough Avenues.

- Bennett Street bridge capacity increase, described below.
- Selected channel improvements downstream from the Bennett Street bridge to Campbell Avenue.

In addition to the three basic alternatives described above, MA evaluated the following alternatives:

1. Construct open channel in Bennett Street right-of-way: This option was excluded because it required the closure of Bennett, an east/west collector that provides system continuity for motorists between Campbell and Ingram Mill. The closure of Bennett Street also restricted access to adjacent residential properties.
2. Relocate Bennett Street and construct new channel in right-of-way: This option was excluded due to the high cost, neighborhood disruption and additional property acquisitions.
3. Various detention alternatives; see Section 7.2 for discussion.

To evaluate all of the alternatives described above, as well as an alternative suggested by property owners in the study reach, the City prepared two computer models. One of these models generates flood flows (and is referred to as a *hydrologic* model) while the second defines floodplain characteristics (width, depth, velocity, etc.) for the given flood flows (this is referred to as a *hydraulic* model). Section 10 of this report provides a detailed review by WWE of the City's hydrologic and hydraulic computer models. WWE thoroughly tested these models and found that they produce reasonable results.

A particular challenge for the City and MA with all of the alternatives has been designing a new Bennett Street bridge over Fassnight Creek. Because the Bennett Street road surface is only about 4 feet above the flow line of the channel, it was difficult for the City and MA to design a bridge that would carry the 100-year flow without overtopping and not cause floodwater to back onto properties south and east of the bridge. Due to this design constraint, consideration was given to relocating or closing Bennett Street between Utah and Jefferson, but this option was not recommended due to the collector status of Bennett Street and its significant daily traffic load. Analysis by the City and MA demonstrates that to accommodate the 100-year flood, without elevating the grade of Bennett Street (which would probably not be feasible), the Bennett Street bridge should consist of a 15-cell box culvert, with each cell having dimensions of 10 feet by 4 feet. These box culverts would span a total width of about 160 feet. Consequently, the Fassnight Channel would need to be widened substantially both upstream and downstream of the box culvert to assure proper flow transitions.

7.2 Feasibility of Upstream Detention

On July 9, 2003, representatives of the City and neighborhood met to discuss the alternatives. Councilmen Bob Jones and Gary Deaver were present, and Mr. Deaver chaired the meeting. This meeting had been requested by Messrs. Larry Barnett (1423 S. Kimbrough) and David Dugan (1410 S. Kimbrough), on behalf of the University Park Neighborhood Association (UPNA). Mr. Barnett serves as the President of the UPNA while Mr. Dugan is Secretary of the UPNA. Based on information provided to WWE by the City, during the July 9th meeting, Mr. Dugan stated that he and the UPNA wanted an alternative to be evaluated that would preserve the homes along the south side of Bennett. The City noted that they began to develop the project with few house removals, but determined that it would not be feasible to construct a box culvert with 100-year capacity. This prompted Mr. Dugan to suggest that the City should evaluate the feasibility of four upstream detention locations, to reduce Fassnight flood flows in the study area. These locations were:

1. An unspecified area of the St. John's Hospital Property.
2. The Park Board land southwest of National and Bennett.
3. The City property immediately west of the art museum parking lot.

4. The Park Board land in the vicinity of the wading pool in Phelps Grove Park.

Prior to the July 9th meeting, Public Works had investigated the possibility of upstream regional detention and determined that it did not appear to be feasible. Studies, by the City, of detention basins in Springfield show that a rule of thumb exists for identifying potential regional detention basins to reduce downstream flows by 50% to 75% as needed in this case. Generally, 20 acre-feet (AF) of detention storage are required for every 100 acres of developed drainage area. Because detention areas typically average 2 feet to 4 feet of depth, 5 to 10 acres of land are needed for construction of detention for every 100 acres of urbanized watershed. For the Fassnight watershed of about 1,800 acres, an area of 90 to 180 acres would be required to reduce flows necessary to provide flood protection. Through studies of detailed aerial photographs, topographical contours and property ownerships, Public Works determined there were no possible opportunities for regional detention basins in the Fassnight watershed to meet the objective of 100-year flood protection in the project area.

Nevertheless, Public Works proceeded with a detailed study of the four locations specified by the UPNA to determine the potential for flood reduction in the project area, both individually and in combination, and to estimate the cost of construction of the basins. In summary:

1. The St. John's campus has met all stormwater regulations so any detention improvements on the site would likely be completely at City cost (taxpayer expense). The site has been completely developed so construction would be expensive and possible only with St. John's cooperation. Approximately 6 AF of detention storage could reduce flows from the 40-acre drainage area by about two-thirds. A 100-year peak flow reduction of about 6% would result at Holland Avenue, which translates into a reduced 100-year flood depth of well under 0.5 feet. The preliminary construction cost estimates range from $1.0-$2.3 million, depending on whether open or enclosed detention would be feasible. Costs could

be higher due to numerous unknowns that could ultimately be significant. Due to the high cost and low benefit, this option is not feasible.

2. Park Board land southwest of National and Bennett between the tennis courts and the landscape display was studied. It was determined that 1.9 acres of land could be excavated and the existing box culvert removed to produce approximately 9.8 AF of storage. The reduction in 100-year peak flow at Holland Avenue would be less than 1%, with an insignificant decrease in flood depth. The preliminary construction cost estimate is $312,500, which does not include any cost for use of the land. It is not known if the Park Board would permit use of the land for this purpose. WWE's assessment of this site is that the benefits are far too small to justify such a large expenditure.

3. The City land immediately west of the art museum parking lot was studied. It was determined that 1.9 acres of land could be excavated to produce approximately 7.4 AF of storage. The reduction in 100-year peak flow would be less than 1% at Holland Avenue, with an insignificant decrease in flood depth. The preliminary construction cost estimate is $208,750. This project would involve the removal of what appears to be a historic amphitheater. The history of the facility is not known and it is not known if removal of this facility for this purpose would be acceptable to the public. WWE's assessment of this site is that the benefits are far too small to justify such a large expenditure.

4. Park Board land east of the Lutheran Church and along the south of Phelps Grove Park was studied. The location of the wading pool is too small to develop a detention basin, but the larger area east of the pool to Virginia Avenue was studied. It was determined that 5.2 acres of land could be excavated to produce approximately 33 AF of storage. The reduction in 100-year peak flow would be less than approximately 5% at Holland Avenue, for a flood depth reduction of far

less than 0.5 feet. The preliminary construction cost estimate is $512,500 which does not include any cost for use of the land. The site currently has about 50 mature trees and a walking trail that would be removed as part of the project. It is not known if the Park Board would permit use of the land for this purpose or if such a project within a park would have public acceptance. WWE's assessment of this site is that the benefits are far too small to justify such a large expenditure.

Detention basin options 2, 3 and 4 considered in combination would reduce the 100-year peak flood elevation in the study reach by less than 0.5 feet. The preliminary construction cost of the three options totals about $1,034,000, which does not include any cost for the use of Park Board property. Considering the minimal benefit that would be received for a $1 million expenditure and the high likelihood of a negative public view of these projects, Public Works would not recommend that any of these sites be developed as detention basins for the purpose of controlling flooding in the study reach. WWE agrees with this conclusion.

7.3 Additional Elements of Flood Control Suggested by Property Owners/Residents in Study Reach

During the July 9, 2003 meeting, Mr. Dugan (again on behalf of the UPNA) stated that in addition to the four detention facilities described in 7.2, above, the following improvements should be studied by the City:

1. Improve the conveyance capacity of the channel downstream from the Bennett Street bridge, because this area acts as a "bottleneck" to flow, and backs water up into the neighborhood.

2. Increase the capacity of the Bennett Street bridge.

3. Increase the capacity of the channel between the Bennett Street bridge and Jefferson Avenue, or at least better maintain the existing channel.

A brief evaluation of these recommendations from Mr. Dugan and the UPNA is as follows:

- The UPNA is correct when it indicates that the channel downstream from the Bennett Street bridge needs to be improved. The City's preferred option includes this feature. However, hydraulic modeling conducted by the City indicates that the major cause of water backing up in the reach between the Bennett Street bridge and Jefferson Avenue is the Bennett Street bridge, itself. Even if there were no downstream obstructions, the flooding situation between the bridge and Jefferson Avenue would be essentially the same as it is now. In addition, City staff have discussed the feasibility of modifying the channel downstream of the Bennett Street bridge with representatives of the USACE and Missouri Department of Natural Resources (MDNR). Although the USACE and MDNR are willing to work with communities to reduce flood risk, there are still environmental permitting constraints associated with any proposals of this kind. Both of these governmental entities encourage methods that restore streams to natural conditions, and which preserve existing vegetation.

- The UPNA is correct that the capacity of the Bennett Street bridge must be significantly increased. As discussed in Section 5, the bridge is currently far undersized. The difficulty posed by the short vertical distance (height) between the top of the existing bridge and the bottom of the Fassnight Channel is demonstrated in Table 5. Table 5 assumes that a 5-cell box culvert with dimensions 8 feet wide by 3.5 feet high is installed (this can be contrasted with the two existing box culverts which are 10 feet wide by 2.5 feet high). Table 5 assumes that the current road grade is not altered.

- A significant constraint to widening this bridge is right of way. There is little room available for widening the bridge to the east or west before encountering private property, not only for the bridge, itself, but also for upstream and downstream channel transitions. The upstream channel transition (expansion) is particularly difficult because it needs to occur on a tight curve and due to the proximity of the adjacent house.

Table 5[1]

Bennett Street Overtopping Depths, Assuming that Crossing Capacity is Upgraded to Include 5-Cell Box Culvert (each cell 8 feet wide X 3.5 feet high)[2]

Storm Event (Year)	Flood Overtopping Depth (ft.)	Flow Velocity (ft./sec)
1-year	0.3	1.7
2-year	0.7	3.1
25-year	1.6	3.4
100-year	2.2	3.6

1 Based on analysis by MA and City.
2 Assumes no debris at culvert entrance. Also assumes current Bennett Street road elevation does not change.

Although the capacity of the channel between the Bennett Street bridge and Jefferson Avenue could be increased by lining and stabilizing the channel banks, WWE's field inspection indicates that it would not be practical to significantly widen the channel because there is so little room between the north side of the channel and the houses on the south side of Bennett Street. There are also space constraints on the south side of the channel in this reach (proximity of homes). Channel widening in this reach could compromise the structural integrity of one or more residences. The sharp bend in the channel immediately upstream of the Bennett Street bridge, in conjunction with the inadequate Bennett Street bridge capacity, are complicating factors. In addition, enlarging this channel reach would provide little benefit east of Jefferson Avenue.

7.4 Preferred Alternative

The City and MA evaluated the advantages, disadvantages and costs of all of the alternatives described above, including alternatives suggested by current property owners in the study reach. The City and MA determined that the 100-year open channel option which leaves the two existing 12 feet by 5 feet box culverts in place is the preferred option. Specific proposed improvements are as follows. All of these would be designed to convey the 100-year flood:

1. Campbell to Bennett—increase existing channel capacity, by either widening existing channel or constructing new channel, roughly parallel to existing channel.

2. Bennett Street bridge—construct new box culverts with additional capacity.

3. Bennett to Jefferson—acquire flood-prone properties, construct new open channel.

4. Jefferson Crossing—add triple box culvert with each cell 12 feet wide by 5 feet high.

5. Roanoke Crossing—delete crossing and close the street.

6. Holland Avenue to Kimbrough Avenue—add triple box culvert with each cell 12 feet wide by 5 feet high.

The recommended project phasing begins downstream and proceeds upstream:

1. Campbell to Bennett—improve existing conveyance capacity in a manner suitable to USACE and MDNR, possibly by widening the channel to one side and by using “bioengineered” channel stabilization methods to promote a “natural” appearance and maintain a riparian corridor.

2. Bennett Street—construct box culverts with additional capacity.

3. Bennett to Jefferson—acquire flood-prone properties, construct grass/modular block channel.

4. Jefferson Avenue—construct triple box culvert, to supplement existing culvert.

5. Jefferson to Kimbrough—acquire flood-prone properties, construct grass/modular block channel.

6. Kimbrough to Holland—acquire flood-prone property, construct triple box culvert adjacent to existing culvert in vicinity of the Trinity Lutheran Church.

In total, about 20 properties would need to be acquired, with the exact number to be determined during final design. Real estate and construction costs are estimated to total approximately $3 million. Funding for improvements from Jefferson Avenue to Campbell Avenue was provided by the 1999 Stormwater Bond Issue, while the 2001 Stormwater Bond Issue provided additional funding to extend the project from Jefferson Avenue to Holland Avenue. This addition was partially attributable to the large flood of 2000. Helpful background information regarding these bond issues was provided to WWE by Ms. Linda Barnett, a neighborhood resident and member of the UPNA.

7.5 WWE Analysis of Alternatives Evaluated

WWE has reviewed the various alternatives that were defined by the City, MA and property owners in the study reach. In addition, following the October 21, 2003 field meeting between Mr. Jones of WWE and neighborhood residents/property owners, WWE recommended that the City conduct additional analysis regarding the feasibility of controlling smaller, frequent events, such as the 2- to 5-year storm. WWE's view was that although such an approach would not address the 100-year flood, the existing flood risk in the reach between Jefferson Avenue and the Bennett Street bridge could be reduced without the need to acquire (remove) any of the homes.

The City analyzed this approach and provided WWE with their analysis. The City's analysis demonstrated the following major points:

- It would be feasible to increase the Bennett Street bridge capacity up to about a 1-year flood without overtopping (see Table 5). The 2-year flood would cause overtopping. The new bridge could not be widened more without impacting the adjacent houses to the point where property acquisition would come into play.

- With a new Bennett Street bridge in place (with 1-year capacity), overflow velocities during the 2-year through 100-year floods would range from about 1.7 to 3.6 feet per second (see Table 5). The resulting combinations of depths and velocities would be unsafe, based on engineering reference/review and WWE's interviews with national experts (see Section 8).

- Concrete lining the channel from Bennett to Jefferson would increase velocities through this section to the point of increasing overtopping velocities at the Bennett Street bridge, under certain conditions. In addition, WWE is concerned that concrete lining this reach of the channel might increase the potential for a hydraulic jump (abrupt increase in water surface elevation) to occur at the sharp downstream bend in the channel, and this would not be acceptable design practice.

- WWE asked the City to evaluate the feasibility of increasing the head (water surface elevation) on the two existing 12-feet-wide by 5-feet-high box culverts at Holland Avenue. This approach would push 20%-30% more flow through the boxes, but it would also increase velocities in the channel between Jefferson and Bennett during events exceeding about a 2-year storm. This concept would also create additional backwater east of Holland, which could be problematic for property owners in that area.

WWE considered the potential for flood-proofing homes in the study reach as a means of either avoiding the need for major channel construction, or reducing the scope of such construction. Flood-proofing measures include such activities as elevating doorways, sealing low windows, elevating structures, etc. to reduce a structure's susceptibility to flooding damages. FEMA recognizes elevating structures and relocation as flood-proofing techniques for residential structures. Flood-proofing is not feasible in the relevant reach of Fassnight Creek, for the following reasons:

- Utilized on such a large scale, the practice would not be consistent with the objectives and mandates of FEMA and the National Flood Insurance Program.
- The significant safety issues associated with flooding would not be addressed by flood-proofing.
- Flood-proofing does not address the underlying problem—inadequate conveyance capacity for frequent and infrequent flood events.

It is also important to note that current regulations would not permit residential or commercial structures within a designated FEMA floodway or within the 100-year floodplain, without the lowest floor being elevated at least 1 foot above the 100-year flood elevation (a basement or crawlspace would be considered the lowest floor).

In summary, although the frequent flood alternative requested by WWE would reduce the frequency of overtopping at the Bennett Street crossing, and would not require house acquisition, the frequency and magnitude of overtopping at that location would still be unacceptable. In addition, as noted above, this approach could create new problems and would not provide an improved level of protection beyond roughly a 2-year storm. Flood-proofing is not feasible. For these reasons, WWE has concluded that the City's preferred option (summarized in Section 7.4) is the most feasible alternative and the one that should be pursued.

8.0 FLOODPLAIN POLICY QUESTIONS

In the course of conducting our evaluation, a number of significant questions related to floodplain policy have arisen. These questions include the following:

1. From the standpoint of acquiring properties that are in a 100-year floodplain, is there a distinction between basement or crawlspace flooding and first floor flooding?

2. Is there a distinction between sanitary wastewater which enters a residence under flooding conditions (due to the sanitary sewers surcharging and backing-up into the basement) versus floodwater not associated with sanitary sewers?

3. The current Flood Insurance Rate Map (FIRM) stops the flood hazard area at Jefferson Avenue, yet the Fassnight Creek watershed is approximately 2.8 square miles in size upstream from this location. Is this consistent with standard FEMA map preparation procedures? In other words, where does FEMA typically terminate a FIRM?

4. When a municipality is aware of special flood hazard areas (areas within a 100-year floodplain) that have not been mapped, what is the obligation of the municipality to address the issue? What means are available for the municipality in this regard?

5. Are municipal floodplain acquisition programs typically voluntary in nature? Under what circumstances will a municipality condemn properties?

6. What is FEMA's policy for hydraulic evaluation of large underground box culverts with respect to debris accumulation, leading to conveyance capacity reduction?

7. What is the allowable risk of overtopping of bridges, such as the Bennett Street bridge, in terms of frequency, depth and velocity?

To obtain answers to these questions, WWE interviewed recognized experts in floodplain management and reviewed relevant literature such as FEMA regulations and standard engineering reference books. Some of the experts were asked all of the questions listed above, while other interviews focused on specific questions. The floodplain experts who we interviewed include:

- **Curt Chandler, P.E**.—Senior staffer with Henderson, Nevada who previously worked for FEMA in Washington, D.C., where he prepared regulations for the National Flood Insurance Program, and who is nationally recognized in flood hazard reduction.

- **Ronald Flanagan**—R.D. Flanagan Associates in Tulsa, Oklahoma. Mr. Flanagan has major responsibility for the City of Tulsa's award-winning flood hazard reduction program. Tulsa has the highest rating from FEMA of any municipality in the United States for flood hazard mitigation/preparedness.

- **Ronald Rossmiller, Ph.D., P.E.**—Previously professor of civil engineering at Iowa State University and National Stormwater Director for HDR, Inc., a leading engineering firm. Dr. Rossmiller has instructed continuing engineering education courses for over 25 years at the University of Wisconsin and frequently addresses floodplain management.

- **Michael Ports, P.E., P.H.**—Principal with Black and Veatch Consulting Engineers in Kansas City, Missouri. Mr. Ports has practiced for over 30 years, and much of his work has focused on the National Flood Insurance Program, for FEMA. Mr. Ports is a national expert in this subject area for the American Society of Civil Engineers (ASCE).

- **Robert Houghtalen, Ph.D., P.E.**—Dr. Houghtalen is Professor of Civil Engineering at the Rose-Hulman Institute of Technology in Indiana. He instructs continuing engineering education classes around the United States for ASCE on floodplain modeling and management, and is co-author of two leading engineering references in this area. He previously worked for FEMA.

- **Brian Hyde, P.E.**—Senior Staff Member with the Colorado Water Conservation Board and recognized authority on floodplain management. Mr. Hyde has been very active with publishing and speaking nationally in this subject area.

- **Allen Taylor, P.E.**—Director of the City of Boulder, Colorado Floodplain Management Program. Boulder is recognized nationally as a leader in flood hazard reduction and floodplain management and Mr. Taylor has considerable experience with the questions listed above. Mr. Taylor is also active in national professional societies that address flood hazard reduction.

- **George Ridel, C.F.M.**—Floodplain Management and Mitigation Branch Manager, Missouri State Emergency Management Agency. Mr. Ridel has extensive experience and understanding of floodplain management and acquisition issues in the state of Missouri.

- **John Liou, Ph.D., P.E.**—Chief Hydrologist, Federal Emergency Management Agency, Region 8, long-time and highly recognized authority on the National Flood Insurance Program.

- **David Mallory, P.E.**—Senior Project Engineer, Denver Urban Drainage and Flood Control District (UDFCD). Following eight years of work experience in the private sector, Mr. Mallory became a staff member of the UDFCD, where he now has a leading role in floodplain management issues for the 42 cities and counties within the Denver Metropolitan Area.

- **Diana Herrera**—Federal Emergency Management Agency-National Flood Insurance Program Bureau and Statistical Agency, Houston, Region 6. Ms. Herrera has expertise on the National Flood Insurance Program.

Based on interviews with the individuals listed above, as well as literature reviews, the key policy-related questions can be answered as follows.

1. From the perspective of floodplain regulators, there is no practical distinction between first floor flooding and basement/crawlspace flooding. If a structure is in a 100-year floodplain and water can get into the structure, there is flood risk. From the specific standpoint of floodplain acquisition programs, there is no distinction between properties that have first floor flooding versus those that only have basement or crawlspace flooding.

2. From a FEMA regulatory perspective, there is no distinction between sanitary wastewater which enters a home during a flood and floodwater from surface sources.

3. FEMA normally defines regulatory floodplain/floodway boundaries for areas that are 1 square mile in size and larger, or where the floodplain width is at least 200 feet. The Fassnight Creek drainage area from Holland Avenue upstream is 2.8 square miles in size and the floodplain width throughout much of the reach between Holland and Campbell is wider than 200 feet. Thus, this reach of Fassnight Creek should have been included on the 1991 FIRM.

4. When a municipal government is aware of an area that should be included on a FIRM but is not included, the municipality does have responsibility to take one or more of the following actions:

- Prepare a "Letter Of Map Amendment" (LOMA) and submit the LOMA to FEMA for review and approval.

- Notify FEMA and request that FEMA update the floodplain mapping.

- Prepare city floodplain maps that include the area in question. For example, the City of Tulsa maintains comprehensive floodplain maps which depict both the FEMA-determined floodplains and floodplains determined by the City. The City determines flood risks and makes other decisions related to floodplain management based on the information contained on these maps.

- Notify property owners that they are in a 100-year floodplain, whether or not their properties appear on the relevant FIRM. Encourage them to purchase flood insurance.

- Proceed with steps necessary to reduce flood hazards in the relevant area.

5. Municipal floodplain acquisition programs are almost exclusively voluntary. Floodplain acquisition programs funded with federal or state funds are required to be voluntary. Municipalities performing floodplain acquisition exclusively funded locally have more flexibility with acquisition programs and can condemn properties under the power of eminent domain, when the proposed improvements clearly benefit public health, safety and welfare (i.e., are performed for the "public good").

6. Culverts are normally evaluated as unobstructed if there is no evidence to the contrary. When a municipality or community can demonstrate that a culvert has experienced past blockage, the culvert should be modeled with an appropriate reduction factor. If a locality is aware of blockage, the municipality would typically inform FEMA and the FIRM would be reevaluated based on the quality of the evidence.

7. Design of the new Bennett Street bridge should address the 100-year flood. Risks to pedestrians or people in vehicles in the 100-year flood and smaller events should be minimized to the maximum extent practical. Assured emergency vehicle access is especially important. See Section 5.5 for recommended overtopping criteria from the ASCE and Water Environment Federation (WEF).

9.0 SUMMARY OF PROPERTY OWNER QUESTIONS, CONCERNS AND CRITICISMS

Many questions and concerns have been raised by property owners near Fassnight Creek in the reach between Holland Avenue and Campbell Avenue regarding the proposed project. These have been expressed directly to City staff via conversations and correspondence, in questionnaires that approximately 20 homeowners responded to (and which were provided to WWE by Mr. David Dugan), and in conversations and correspondence with WWE. Of particular value to WWE was an October 21, 2003 field meeting that Jonathan Jones of WWE had with approximately one dozen residents, which included a driving tour of the Fassnight Creek watershed conducted by David Dugan and Larry Barnett, followed by a walking inspection of the Fassnight Creek channel, from Jefferson Avenue to a location downstream from the Bennett Street bridge. In addition, Mr. Dugan has provided substantial background information to WWE, which has been quite valuable, and many long-term residents of the neighborhood provided important information regarding flooding history. Mr. Greg Davison, who resides on the north side of Bennett Street between Jefferson Avenue at the Bennett Street bridge, videotaped two flood events (July 3 and 12, 2003). We have reviewed this video footage to better understand how floodwaters move through the study area and to check the hydrologic and hydraulic computer models of Fassnight Creek that were originally developed by the City.

Although many of the comments made by property owners were critical of the City's handling of the proposed project, project features, or both, other comments have been neutral or supportive of the project and/or the City. Indeed, the neighborhood questionnaires and other documents that we have reviewed and our interviews, provide a broad range of perspectives and questions from property owners in the study reach, ranging from those adamantly opposed to relocating to those prepared to promptly relocate.

Based on our review of correspondence, meeting notes, telephone conversation notes, and information provided to us by Messrs. Dugan and Barnett, WWE's understanding of the major criticisms of the project is as follows. Section 9 identifies the criticisms while Section 11 addresses them.

1. There has been poor communication from the City to the neighborhood. Communications have been inadequate, inconsistent, and in general, lacking an appropriate level of explanation.

2. The flooding problem has been overstated by the City. What really exists here is a case of nuisance flooding, which occurs all over the city. The City's hydrologic computer model for Fassnight Creek calculated peak flows that are unrealistically large.

3. This is a classic case where "the cure is worse than the disease." The City's proposal goes well beyond what is necessary to address the problem. Messrs. Dugan and Barnett, speaking on behalf of the University Park Neighborhood Association, have repeatedly stated that they desire an option that preserves the homes along the south side of Bennett Street.

4. The City's "mind is made up" that this project must move forward given the history of the relevant bond issue. There are many factors that are prompting the City to want to move ahead with this project, in addition to flood control. The City should have canvassed the neighborhood before specifying that bond monies would be allocated toward improving the Fassnight channel in the study reach.

5. Although everyone who we have spoken to agrees that safety is a legitimate issue, especially the frequency and magnitude of flooding at the Bennett Street bridge,

neighborhood safety can be significantly improved without a project of this magnitude.

6. Although there is regular flooding of streets and yards in the study reach, the depths are not significant and the duration of flooding is short.

7. Sanitary sewer backups are a significant source of the water in basements, and such backups can be addressed without the proposed project, primarily through the diligent installation of backwater valves.

8. The City has drawn attention to the flooding problem in the study reach and has thereby reduced property values.

9. The City should not be calling attention to the fact that the 100-year floodplain should have been extended farther upstream on the 1991 FIRM. Formal designation of a larger area as “Zone A” (regulatory floodplain) will cause problems for property owners who suddenly find themselves in Zone A.

10. Due to inaction over the past approximately ½ year, the City has left homeowners in a state of limbo; it has not provided a clear statement of how it intends to proceed.

11. The City has allowed development to occur in the watershed without detention, so peak flows have increased. The City has over-utilized the detention “buy-out” (fee in lieu of) program.

12. The Fassnight Channel is not properly maintained.

13. The flood risk is greater downstream from Jefferson Avenue than upstream from Jefferson Avenue.

WWE has accounted for all of these concerns with our evaluation. As discussed in Section 7, the City, MA and WWE also evaluated the alternative proposed by Mr. Dugan on behalf of UPNA. Section 11 provides our evaluation of the concerns listed above.

10.0 EVALUATION OF CITY HYDRAULIC AND HYDROLOGY MODELS

Section 10 summarizes WWE's review of the City's hydraulic (floodplain delineation) and hydrologic (flood flow quantification) and models. The models used by the City, HEC-RAS and HEC-1, were developed by the federal government and are widely used and well accepted. The selection of these models was appropriate. Their application by the City was reasonable. The few specific changes provided below are minor, and in the category of "fine-tuning." In fact, if anything, the City's modeling tends to understate the depth, velocity and extent of flooding in the study reach in the 100-year flood. We asked City staff about this, and they responded that they wanted to assure that flood risks would not be overstated by the modeling.

To review the adequacy of the City's models, they were loaded onto WWE's computers and thoroughly utilized and tested. WWE checked model input and output values for reasonableness. WWE has back-up computer files, both electronic and hard copy. WWE will be pleased to provide this information to reviewers upon request. Selected information is provided in Appendix A.

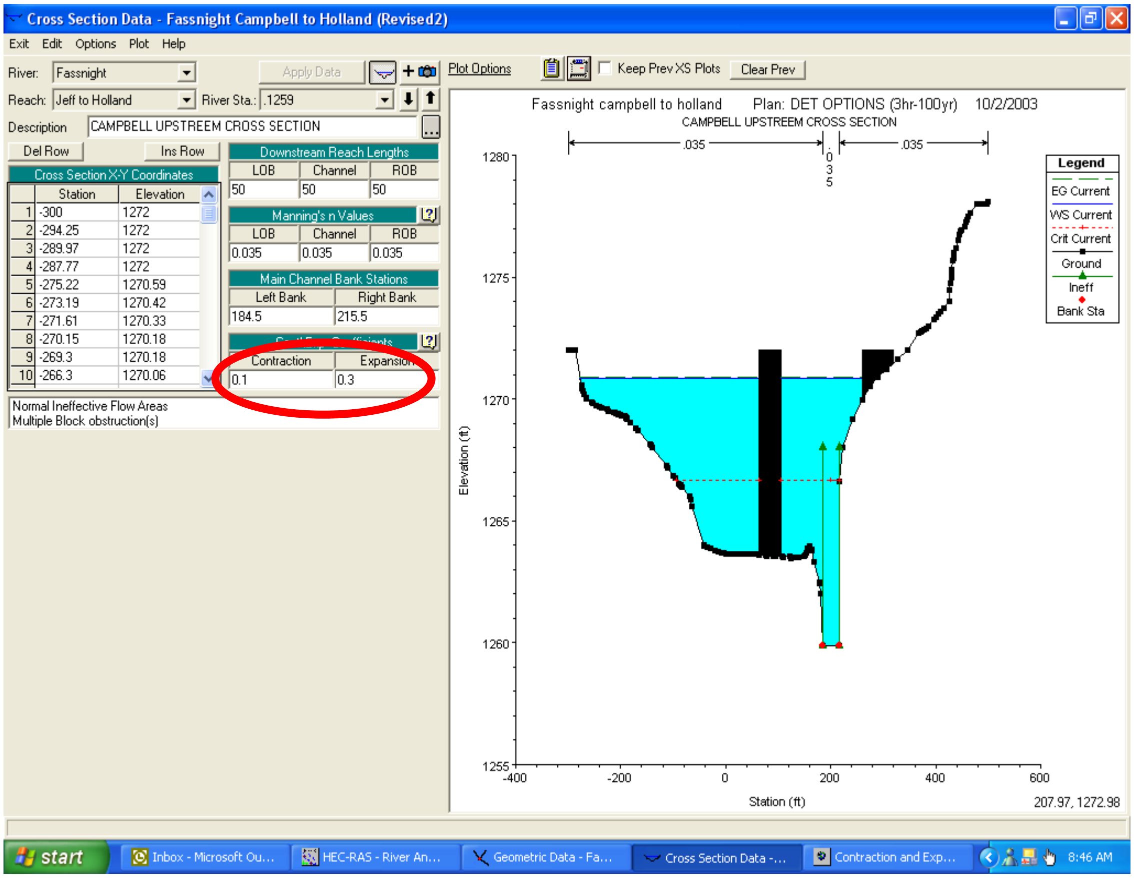
10.1 Hydraulic Model (HEC-RAS)

10.1.1 Bridges/Culverts

Expansion and contraction coefficients—Figure 2, shows that the expansion and contraction coefficients are, respectively, 0.3 and 0.1. Typical expansion and contraction coefficients upstream and downstream of bridges are usually closer to 0.5 and 0.3. An example model profile is included in Figure 2. For abrupt transitions, more typical coefficients would be 0.8 and 0.6. This observation is characteristic of cross-sections immediately upstream and downstream of bridges in all of the Fassnight Creek model runs. This modification should not significantly change the model results, but could cause a slight increase in water surface elevations upstream of the bridges.

Figure 2

Fassnight Creek HEC-RAS Cross-section Upstream of Campbell Street Bridge



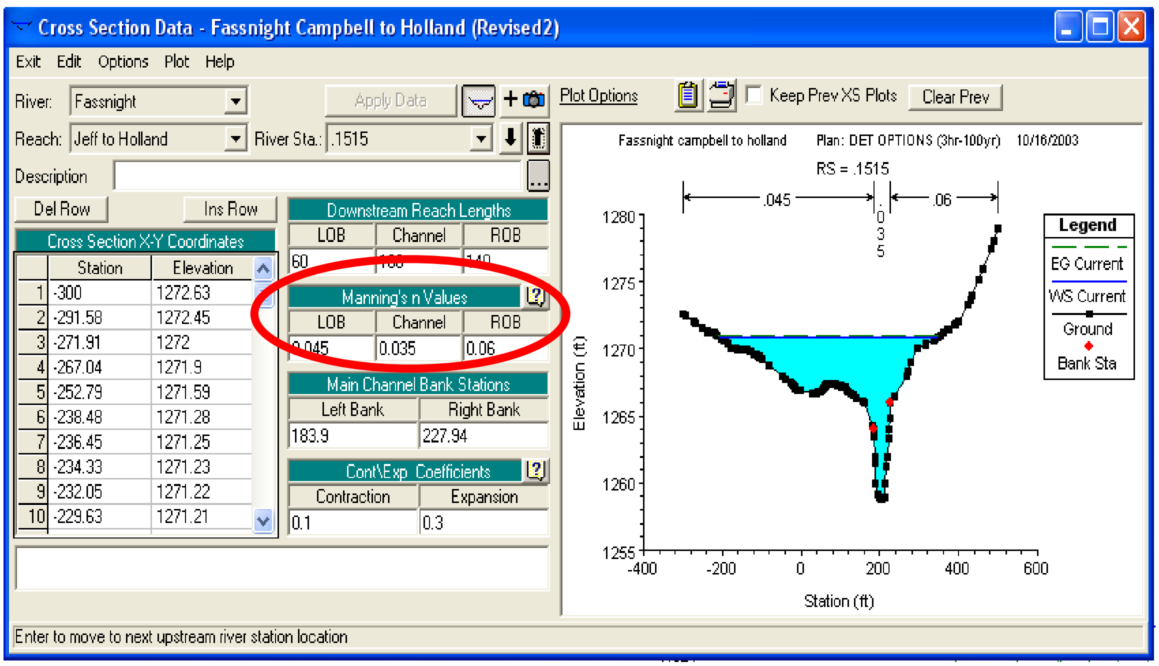
10.1.2 Channel Manning's "n" Factors (Friction Factor)

Manning's n values appear to be low in some reaches, particularly for the reach from Bennett Street to Campbell Avenue. For example, the Manning's n for this reach ranges between 0.02 and 0.06, which is low based on field inspection and photographs. An example model cross-section from this reach is provided in Figure 3. All model results and comparisons are shown in the tables provided by the City of Springfield with the modeling package and in the Fassnight manning summary.xls spreadsheet, provided in Appendix A.

The implications of under-estimating friction factors are significant, because the City calibrated their HEC-RAS model to measured flood depths in the July 12, 2000 flood, and described this as a 100-year flood. Had higher friction factors been utilized, which would have been justified a selected cross section, the subject flood would have been characterized as less severe than the 100-year flood. This subject is discussed in Section 5.4.2.

Figure 3

**Fassnight Creek HEC-RAS Cross-section
In Reach Between Bennett Street and Campbell**



10.1.3 Bank Station Locations

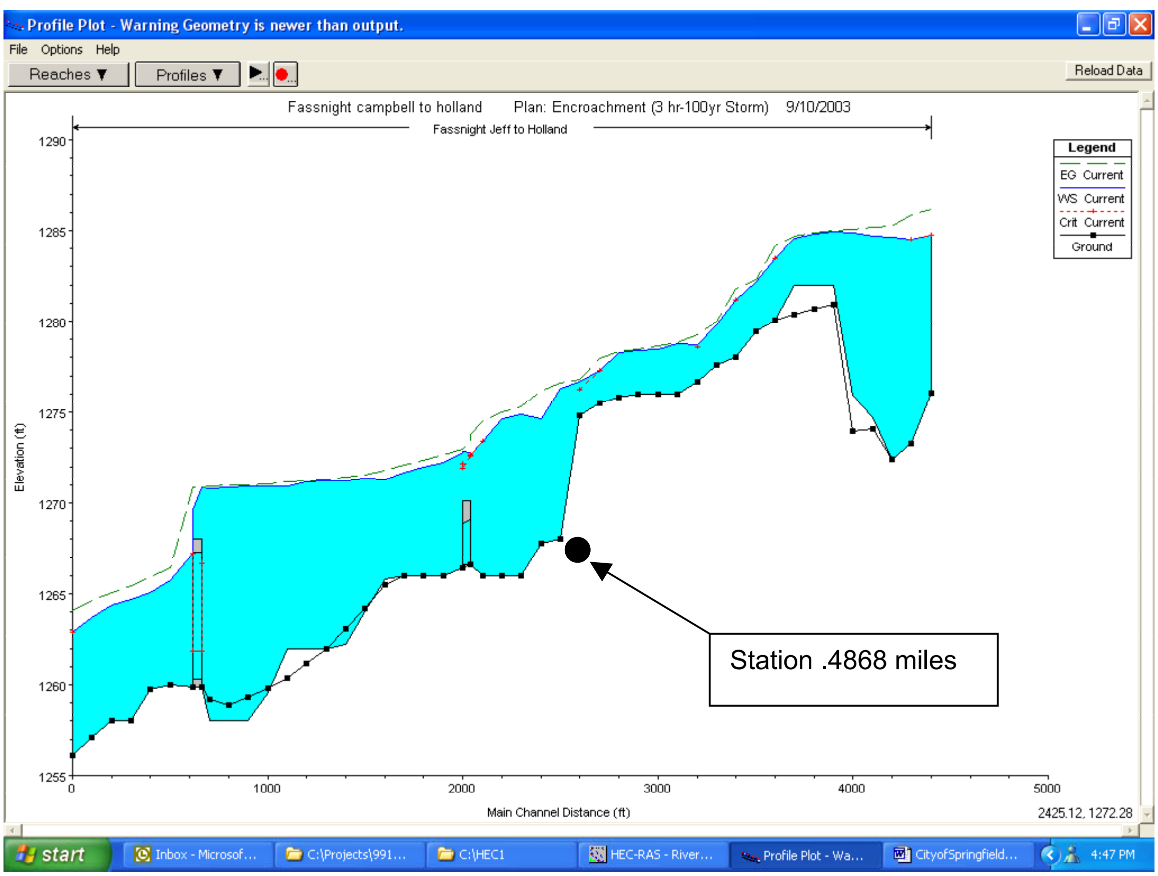
Bank stations in the reach from Holland to Jefferson Avenue (0.4924 - 0.7386) appeared to be in inappropriate locations. Each cross-section was subdivided into more than three sections in each of the models; therefore, bank station locations should not affect water surface elevations for this reach. However, the bank station locations will affect the model output. WWE recommends moving bank stations to more appropriate locations for this reach. Bank stations for all other reaches appear to be in appropriate locations. Although this change should be made, model results are not affected.

10.1.4 Hydraulic Profiles

The hydraulic profile for the Encroachment (3-hr, 100-year) storm appears to demonstrate that one cross-section station is missing. WWE has indicated the apparent location in Figure 4. We recommend that this cross-section be added for the sake of consistency between models. The cross-section that appears to be missing is located at river station 0.4868, at the Jefferson Avenue culvert outlet. All other hydraulic profiles appear to be reasonable.

Figure 4

100-year, 3-hr Encroachment Water Surface Profile



10.1.5 Cross-Sections

Cross-section selection and spacing appear to be reasonable and consistent with general floodplain modeling practices.

10.1.6 Boundary Conditions

A critical depth boundary condition was used for all model runs. A critical depth boundary condition should be a reasonable assumption for all of the HEC-RAS model runs.

10.1.7 Ineffective Flow Areas

Ineffective flow areas were input upstream and downstream of all culverts and appeared to be placed at rational locations.

10.1.8 Flow Input Values

Flow input values for model frequencies were spot checked against the *Fassnight Summary.xls* spreadsheet for the *DET OPTION (3-hr, 100-year storm)* HEC-RAS model (see Appendix A). HEC-RAS model input was consistent with the values in the summary spreadsheet. It is unclear where the values at the inflow to the Holland Avenue came from, though they are close to the values from Culvert Master minus the flow at the top of the reach.

10.1.9 Split Flow Areas

For the smaller storm event frequencies (i.e. 5-year), split flow was predicted in some of the cross-sections between Holland and Jefferson Avenue. WWE could not verify that split flow scenarios actually exist based on the topography provided. WWE would recommend taking a closer look at areas of split flow to be sure that these conditions actually exist and are modeled accurately. This should not change model results.

10.2 "Culvert Master" Program—Long Culvert from Holland Avenue to Jefferson Avenue

All model input and output appear to be reasonable for this computer model, which calculates culvert hydraulics.

10.3 Large Printed 3- and 6-hr 100-year Floodplain Maps

WWE reviewed the large floodplain maps that the City printed for us, which are based on HEC-RAS. The floodplain delineations look consistent with HEC-RAS model elevations for the mapped events.

10.4 Hydrologic Model (HEC-1 Model)

10.4.1 Sub-basin Areas

Sub-basin areas were compared relative to adjacent basins for apparent size using the basin delineation map provided by the City of Springfield. All sub-basins areas appeared to be reasonable based on comparative relationships. Sub-basin areas were checked using the attached FSNTDET.OUT HEC-1 output file. (See Appendix A.)

10.4.2 Channel Routing Parameters

WWE performed a channel routing input parameter check on element CRF78 by scaling off of the sub-basin delineation map. Spot checks against the FSNTDET.OUT HEC-1 output file showed that model routing length parameters were reasonable.

10.4.3 Model Network Setup

WWE examined the model network setup using the network line schematic in the HEC1 FSNTDET.OUT file. The model schematic was only checked to model design flow point F11B, which corresponds to the end of the HEC-RAS model segment. The model schematic appeared to accurately reflect the hydrology of the basin. The model schematic was also verified against the sub-basin map.

10.4.4 Curve Numbers and Lag Times

Curve numbers and lag times were not reviewed in detail, but a quick check indicates that they are reasonable. More extensive input data and aerial coverage would be required to perform a more sophisticated evaluation.

10.4.5 Runoff Volumes

A reasonableness check was performed for the total runoff volumes in the hydrologic model by comparing the total rainfall depth and drainage area to runoff volume predicted in the model. Runoff volumes estimated by the HEC-1 model for model location F11B (Near Campbell Avenue) was 55% of the total precipitation volume for the 100-year, 3-hr storm event. This runoff percentage appears to be a reasonable number based on the curve numbers and percent imperviousness of the modeled watersheds.

10.4.6 Runoff Peaks

Peak runoff rates were checked by comparing unit peak runoff rates for the Fassnight Creek watershed to the South Creek watershed. The South Creek drainage area is similar in imperviousness and density of development. A unit peak discharge rate of 1.7 cfs/acre was estimated for the Fassnight drainage for the 100-year, 3-hr event at Campbell Avenue. The unit peak discharge for South Creek was 1.8 cfs/acre at Campbell Avenue. These values compare closely, indicating reasonable runoff peaks for the HEC-1 model.

10.5 Detention Basin Options

10.5.1 Basin Volumes

Scaled measurements were taken from the Fassnight Creek Detention Basin Options figure of detention basins lengths and widths to develop volume estimate approximations. Depths were assumed from the provided basin rating curves. The scaled values versus the values provided by the City of Springfield are summarized in Table 6, below. The "back of the envelope" volume checks closely matched the actual pond volumes.

Table 6

Actual Storage Versus Estimated Storage Volumes for Proposed Fassnight Creek Basins A, B and C

Basin	Actual Volume (Acre Feet)	Estimated Volume (Acre Feet)
A	9.8	10.7
B	7.4	11.7
C	33.2	26.9
Total	**50.4**	**49.3**

10.5.2 Peak Runoff Reduction

A reasonableness check was performed on the ability of 50 AF of storage to reduce the 100-year, 3-hr runoff peak for the Fassnight Creek drainage using the triangular unit hydrograph method. The runoff peak predicted for Fassnight Creek just downstream of the proposed detention site (2.65-square-mile drainage area) was 2,923 cfs and the runoff volume was approximately 416 AF. The triangular unit hydrograph method predicts that 50 AF of storage would have the potential to reduce the runoff peak to 2,570 cfs. This estimated peak reduction would not significantly affect water surface elevations through the Fassnight Creek drainage area. These analyses confirmed the reasonableness of model results predicted by the HEC-1 detention modeling.

11.0 WWE ANALYSIS AND RECOMMENDATIONS

As discussed in Sections 4 and 5 of this report, there is a significant flooding problem on Fassnight Creek in the study reach, between Holland Avenue (upstream) and Campbell Avenue (downstream). The current conveyance capacity of Fassnight Creek, which consists of two 12-feet-wide by 5-feet-high box culverts between Holland Avenue and Jefferson Avenue, and an open channel from Jefferson Avenue downstream to Campbell Avenue, is between a 2-year and 5-year flood. Larger storm events exceed this conveyance capacity and flood the neighborhood in the study reach. The area has a significant flooding history, with major floods in 1951, 1993 and 2000 and numerous smaller floods (which have caused street, alley, yard and basement or crawlspace flooding). Of particular concern is the Bennett Street bridge, which is inundated several times per year in a typical year. As shown on the 1991 FIRM and on 100-year floodplain mapping prepared by the City of Springfield (see Drawing 1), there is a substantial 100-year floodplain through the study reach, and many structures are located in the floodway, as well. In short, by any standard, there is a significant flood risk in the study reach and action of some sort must be taken to mitigate the risks to public health, safety and welfare.

The alternatives that were formulated and reviewed by the City Public Works Department and MA (see Section 7) were reasonable and consistent with standard engineering practice. The City and MA also carefully evaluated alternative proposals made by property owners in the study reach and WWE. Based on all of the alternatives evaluated, WWE has concluded that the City's current "preferred alternative" (described in Section 7.4) should be implemented. The City's proposal to acquire certain homes (on a voluntary basis and at fair market value), followed by construction of open channel and culvert improvements that will convey the 100-year flood, is prudent, consistent with national floodplain management policies, and necessary.

The alternative offered by neighborhood residents (described in Section 7) was logical and helpful; unfortunately, implementing that alternative would not provide an adequate level of flood hazard reduction. As Jonathan Jones explained to the approximately one-dozen property owners who he met with on October 21, 2003, the basic problem with the neighborhood alternative is that it does not address the fact that (in very rough terms) the 100-year flood at Holland is about 3,000 cfs and the existing underground box culverts will convey about 1,000 cfs; this leaves about 2,000 cfs of flow that must move to the west through streets, alleys, yards, basements, crawlspaces, etc.

WWE asked the City to evaluate an alternative that would address smaller, frequently occurring floods. WWE's hope was that such an alternative would significantly reduce flood hazards, while enabling the homes to remain in the study reach. As described in Section 7, there are a number of significant problems associated with this alternative, including the fact that it would not adequately reduce flood risk.

As discussed in Section 8, many important floodplain policy questions arose in the course of this evaluation, for which we sought the advice and counsel of national floodplain management experts, and conducted literature review. We recommend that City officials carefully review Section 8, because the experts' advice indicates that the City should take action in certain areas. Having discussed the Fassnight Creek situation with these experts, we are confident that implementation of the City's preferred alternative would be consistent with sound floodplain management practice, nationally.

Section 9 summarizes major questions, concerns and criticisms posed by property owners in the study reach to the City and WWE. These were valuable. WWE offers the following observations regarding the criticisms raised by property owners:

- Regarding the assertion that neighborhood reaction to the project should have been obtained in advance of the bond issue, the City has indicated to WWE that it agrees with this criticism and will respond by initiating major drainageway master plans in the City, which will include public input and dialogue.

- The City has not overstated the flooding problem in the study reach. The flooding history of the area is well documented and goes back over 50 years. The facts indicate that the area is subject to regular flooding, including large events in 1951, 1993 and 2000.

- WWE fully understands the concern that the City's preferred alternative seems to go beyond what is necessary to address the problem. However, as discussed in Section 7, alternatives were evaluated that address small, frequently occurring events (rather than the 100-year flood) and which would result in fewer home acquisitions. However, despite being expensive to implement, these alternatives would not significantly reduce the 100-year floodplain and would result in an unacceptably high level of risk to public health, safety and welfare.

- The City had many legitimate reasons for assigning this project as one of the highest priority flood control projects in the City. The criteria that the City relied upon include, as examples: number of complaints received; number of homes in the floodplain and floodway; flooding history; assessment of hazard to the public and outside recommendations (such as the 1990 KCM study which identified this reach of Fassnight Creek as the most problematic in the watershed). These criteria are consistent with the national norm for public works departments.

- Property owners acknowledge that there are serious safety issues associated with the Bennett Street bridge overtopping a few times per year, in a typical year; however, they were hopeful that increased channel capacity upstream and downstream and a larger bridge could address this issue. WWE carefully evaluated this possibility. Unfortunately, even if a major project were undertaken to create 1-year bridge capacity, this would still result in unacceptably large overtopping depths and excessive velocities during larger floods.

- WWE can understand the perception of some property owners that flood depths are shallow in much of the study area; however, the City's computer modeling demonstrates that there are 100-year flood depths of 3 feet or more in some areas, and hazardous combinations of flood depths and velocities at many locations in the study reach. In many events, the duration of the flooding is short. However, hydrologic modeling shows that for larger events, high flows can exist for 30 minutes or longer, and this is certainly cause for concern.

- Even if sanitary sewer backups could be prevented in the study reach, the homes that are currently in the 100-year floodplain will continue to be in the floodplain. The nature of surface flooding in both frequent and infrequent storms will not change in response to sanitary sewer system upgrades. It is important for property owners to recognize that backwater valves are not guaranteed to work during floods, require maintenance, and are subject to debris accumulation. Although it is prudent to install such devices for homes located in floodplains (they are required in the 2003 *International Plumbing Code*, Section 715, "where the flood level rims of plumbing fixtures are below the elevation of the next upstream manhole in the public sewer"), they should not be viewed as a "cure-all."

- Some property owners have expressed concern that the City intends to extend official, regulatory floodplain mapping (FIRM) upstream from Jefferson Avenue, thereby placing properties into the regulatory floodplain which are not currently shown on the FIRM floodplain. Our interviews with national experts indicate that the City has a fundamental responsibility to extend floodplain mapping upstream to at least the location where the watershed is 1 square mile in size (roughly, National Avenue). A responsibility of municipal government is to inform the public of areas that are subject to flood risk. There are a number of options that the City has for extending the present floodplain mapping, (see Section 8), and it is not mandatory for this extension to occur via an updated FIRM or "Letter of Map Revision (LOMR)." For various reasons, the preferred approach may be for the City to publish and disseminate its own floodplain maps, independent from FEMA. This would alert residents to the flood hazards, without the potential stigma of a "Zone A" designation. Tulsa, Oklahoma has adopted and published a ***Flood Hazard Atlas***, which has been vital to its flood risk reduction program. The Fassnight Creek floodplain between Jefferson and National Avenues, as defined by the City, should be included in this type of local atlas.

- WWE empathizes with homeowner frustration at being "left in limbo" from late this summer until the date of this report. However, the City put the project on hold so that an outside, independent review (by WWE) could be conducted. This review was primarily stimulated by questions and concerns expressed by community residents and property owners.

- Regarding concerns that the City has allowed development to occur in the watershed without detention and has over-utilized the detention "buy-out" program, WWE observes that the Fassnight Creek watershed was largely developed by 1970. This is not a case where there has been extensive new development within the last decade. The City has not over-utilized detention buy-outs in the Fassnight Creek watershed. Information provided by the Public Works Department demonstrates that 0.74 AF of detention buy-out has occurred in this watershed since 1983, which is insignificant given the magnitude of flooding. For example, 0.74 AF is the necessary 100-year detention volume for about 4 acres of developed land, which is about one-quarter of 1% (0.25%) of the watershed area at Holland Avenue.

- Although the property owners are correct in asserting that the Fassnight Creek channel has not been adequately maintained from Jefferson Avenue downstream, maintenance is currently the property owners' responsibility, as the City does not have maintenance easements for this channel segment. In addition, even if the channel in question were concrete lined and completely clear of debris, there would still be a significant flood risk to the neighborhood given the magnitude of the flood flows. The City does not have maintenance easements for the channel between the Bennett Street bridge and Jefferson Avenue. Also, maintenance between the Bennett Street bridge and Campbell Avenue would require permits from the USACE and MDNR. These regulatory authorities are concerned about maintenance activities that would modify the current "natural" appearance of the channel and riparian corridor and space/easement limitations.

- The flood risk is greater from Jefferson Avenue downstream than it is between Holland Avenue and Jefferson Avenue. However, there is still significant risk in the upstream reach, since the capacity of the existing box culverts is only about the 5-year flood. The extensiveness of the floodplain between Holland and Jefferson is shown on Drawing 1.

The City Public Works Department has stated to neighborhood residents/property owners and to WWE that the City's goal would be to proceed with *voluntary* acquisition of homes that are identified for the preferred alternative to be implemented. In addition, the City recommends that the project be constructed in phases, beginning with Campbell Avenue to the Bennett Street bridge, followed by the bridge to Jefferson Avenue, followed by Jefferson Avenue to Holland Avenue. WWE concurs with the City's approach on both of these points. Just as it is important to acknowledge the views of those property owners who wish to stay in the neighborhood, it is also important to recognize the views of those who would like the City to acquire their properties at this time. Phased implementation is consistent with this philosophy.

WWE has not conducted a benefit/cost (B/C) analysis for the proposed project. Such an evaluation would go beyond the scope of our review. A B/C analysis for the Fassnight Project would likely result in a ratio that is favorable compared to other potential City flood control projects, based on such factors as:

- Large number of properties in the 100-year floodplain (79) and floodway (30) in the study reach.
- Frequency of flooding.
- Number of complaints received by the City.
- Significant safety risks related to bridge overtopping and lack of emergency vehicle access.
- Pubic benefits associated with project (improved public safety, increased flood protection and property values for the neighborhood as a whole, better "connection" of parks, greenway access, less time spent by City staff addressing flooding in the study reach, etc.).

A number of the experts we interviewed suggested that it would prudent for the City to obtain options for those homes where the current owners do not wish to sell. These options would state that at such time as the current property owner decides to sell, the City would have first right of refusal on the property. WWE concurs with this recommendation. In addition, we recommend that the City send letters to property owners who choose to not participate in the voluntary acquisition program indicating that the offer was made, and informing them that they are residing in a high-risk area.

Until the conveyance capacity of the Bennett Street bridge is increased, WWE recommends that the City install signs on both sides of the bridge, warning motorists and pedestrians to not cross the bridge when overtopping is occurring (for suitable sign designs see www.ctre.iastate.edu/pubs/itcd/lowwater.pdf,). We anticipate and understand that some property owners will not concur with this recommendation, but this hazard is so significant that immediate action is warranted, and we do not see a reasonable short-term alternative. We also suggest that the City inform emergency medical services about the flooding status at the Bennett Street bridge, and define alternative access routes.

WWE recommends that the City take steps to extend the present Fassnight Creek floodplain mapping upstream from Jefferson Avenue to at least National Avenue. The City should also suggest that it would be prudent to purchase flood insurance. In short, good communication between City staff and property owners is essential.

We hope that this evaluation has been helpful, and look forward to discussing our findings with all interested parties. Again, we sincerely appreciate the information and assistance provided by community residents and property owners and representatives of the City Public Works Department.

REFERENCES

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APPENDIX A

HEC-RAS Plan: 3 hr storm River: Fassnight Reach: Jeff to Holland Profile: 100 yr

Reach	River Sta	Profile	Q Total	W.S. Elev	Crit W.S.	Vel Chnl	Top Width	Froude # Chl	Mann Wtd Total
			(cfs)	(ft)	(ft)	(ft/s)	(ft)		
Jeff to Holland	0.8333	100 yr	2923	1284.74	1284.74	10.38	296.07	0.69	0.022
Jeff to Holland	0.8144	100 yr	2923	1284.46	1284.46	10.29	279.57	0.67	0.022
Jeff to Holland	0.7955	100 yr	2923	1284.08		7.67	256.46	0.47	0.021
Jeff to Holland	0.7765	100 yr	2923	1284.1		7.69	294.24	0.48	0.025
Jeff to Holland	0.7576	100 yr	1939	1284.41		4.38	414.83	0.26	0.027
Jeff to Holland	0.7386	100 yr	1939	1284.52		2.14	591.2	0.20	0.025
Jeff to Holland	0.7197	100 yr	1939	1284.49		2.25	484.37	0.20	0.030
Jeff to Holland	0.7008	100 yr	1939	1284.44		2.23	465.42	0.20	0.029
Jeff to Holland	0.6818	100 yr	1939	1283.6	1283.6	8.54	259.21	0.95	0.029
Jeff to Holland	0.6629	100 yr	1939	1282.45		2.92	505.99	0.32	0.029
Jeff to Holland	0.6439	100 yr	1939	1281.44	1281.44	9.6	268.61	0.92	0.035
Jeff to Holland	0.625	100 yr	1939	1279.73		5.4	298.26	0.68	0.031
Jeff to Holland	0.6061	100 yr	1939	1278.72	1278.69	7.34	220.48	1.07	0.031
Jeff to Holland	0.5871	100 yr	1939	1278.91		3.29	419.96	0.37	0.040
Jeff to Holland	0.5682	100 yr	1939	1278.66		3.81	250.77	0.42	0.038
Jeff to Holland	0.5492	100 yr	1939	1278.54		3.01	358.45	0.33	0.041
Jeff to Holland	0.5303	100 yr	1939	1278.46		3.19	363.55	0.35	0.035
Jeff to Holland	0.5114	100 yr	1939	1277.55	1277.53	9.18	221.33	1.13	0.036
Jeff to Holland	0.4924	100 yr	3092	1276.57	1276.57	7.44	601.88	1.03	0.028
Jeff to Holland	0.4868	100 yr	3092	1275.13	1274.83	10.67	105.32	0.75	0.033
Jeff to Holland	0.4735	100 yr	3092	1275.18		9.04	308.51	0.64	0.034
Jeff to Holland	0.4545	100 yr	3092	1274.87		9.12	306.07	0.68	0.036
Jeff to Holland	0.4356	100 yr	3092	1274.85		6.56	399.33	0.46	0.043
Jeff to Holland	0.4167	100 yr	3092	1274.78		5.75	416.14	0.38	0.043
Jeff to Holland	0.3977	100 yr	3092	1273.3	1273.3	11.18	312.22	0.80	0.046
Jeff to Holland	0.3864	100 yr	3092	1272.65	1272.65	11.5	323.25	0.82	0.048
Jeff to Holland	0.3826		Culvert						
Jeff to Holland	0.3788	100 yr	3092	1272.78	1272.22	5.7	611.16	0.40	0.034
Jeff to Holland	0.3598	100 yr	3092	1272.28		6.61	482.68	0.54	0.038
Jeff to Holland	0.3409	100 yr	3092	1271.98		6.95	437.78	0.51	0.038
Jeff to Holland	0.322	100 yr	3092	1271.66		6.68	358	0.51	0.035
Jeff to Holland	0.303	100 yr	3092	1271.34		7.07	347.75	0.55	0.036
Jeff to Holland	0.2841	100 yr	3092	1271.33		4.57	353.69	0.33	0.037
Jeff to Holland	0.2652	100 yr	3092	1271.28		4.02	378.75	0.27	0.036
Jeff to Holland	0.2462	100 yr	3092	1271.25		3.76	675.33	0.25	0.046
Jeff to Holland	0.2273	100 yr	3474	1271.13		4.32	538.94	0.27	0.044
Jeff to Holland	0.2083	100 yr	3474	1270.92		5.43	331.72	0.33	0.040
Jeff to Holland	0.1894	100 yr	3474	1270.92		4.42	385.6	0.26	0.041
Jeff to Holland	0.1705	100 yr	3474	1270.89		3.77	564.08	0.22	0.041
Jeff to Holland	0.1515	100 yr	3474	1270.85		3.87	555.15	0.21	0.041
Jeff to Holland	0.1326	100 yr	3474	1270.77		4.4	541.92	0.28	0.035
Jeff to Holland	0.1259	100 yr	3474	1270.85	1267.21	2.28	497.5	0.12	0.035
Jeff to Holland	0.1184		Culvert						
Jeff to Holland	0.1165	100 yr	3474	1267.2	1267.2	15.34	331.32	1.00	0.030
Jeff to Holland	0.0947	100 yr	3474	1265.75		9.05	212.93	0.70	0.033
Jeff to Holland	0.0758	100 yr	3474	1265.04		10.38	242.47	0.86	0.033
Jeff to Holland	0.0568	100 yr	3474	1264.67		9.03	223.18	0.70	0.033
Jeff to Holland	0.0379	100 yr	3474	1264.39		9.03	230.88	0.65	0.033
Jeff to Holland	0.019	100 yr	3474	1263.67		10.72	241.11	0.77	0.033
Jeff to Holland	0	100 yr	3474	1262.91	1262.91	11.25	193.55	0.85	0.033

HEC-RAS Plan: 6 hr River: Fassnight Reach: Jeff to Holland Profile: Current									
Reach	River Sta	Profile	Q Total	W.S. Elev	Crit W.S.	Vel Chnl	Top Width	Froude # Chl	Mann Wtd Total
			(cfs)	(ft)	(ft)	(ft/s)	(ft)		
Jeff to Holland	0.8333	Current	2124	1282.91	1282.91	11.58	97.15	0.9	0.018
Jeff to Holland	0.8144	Current	2124	1282.18	1281.53	12.15	28.53	0.86	0.018
Jeff to Holland	0.7955	Current	2124	1283.24		6.62	207.36	0.43	0.019
Jeff to Holland	0.7765	Current	2124	1283.14		7.18	261.84	0.48	0.022
Jeff to Holland	0.7576	Current	1010	1283.52		2.91	354.79	0.18	0.024
Jeff to Holland	0.7386	Current	1010	1283.57		1.7	514.61	0.19	0.024
Jeff to Holland	0.7197	Current	1010	1283.55		1.66	401.33	0.17	0.029
Jeff to Holland	0.7008	Current	1010	1283.51		1.62	379.46	0.16	0.029
Jeff to Holland	0.6818	Current	1010	1282.79	1282.79	7.4	142.64	1	0.028
Jeff to Holland	0.6629	Current	1010	1281.47		2.86	411.99	0.4	0.028
Jeff to Holland	0.6439	Current	1010	1280.54	1280.54	8.1	157.7	0.91	0.03
Jeff to Holland	0.625	Current	1010	1279.09		4.32	268.31	0.66	0.031
Jeff to Holland	0.6061	Current	1010	1278.14	1278.14	5.83	199.84	1.1	0.031
Jeff to Holland	0.5871	Current	1010	1278.02		2.43	343.22	0.35	0.038
Jeff to Holland	0.5682	Current	1010	1277.84		2.69	227.34	0.36	0.036
Jeff to Holland	0.5492	Current	1010	1277.76		1.98	306.36	0.26	0.038
Jeff to Holland	0.5303	Current	1010	1277.71		2.22	315.99	0.29	0.034
Jeff to Holland	0.5114	Current	1010	1277.33		5.53	210.78	0.72	0.035
Jeff to Holland	0.4924	Current	2256	1276.39	1276.39	6.61	577.88	0.98	0.028
Jeff to Holland	0.4868	Current	2256	1274.58		9.45	75.27	0.7	0.033
Jeff to Holland	0.4735	Current	2256	1274.47	1274.47	8.83	222.02	0.66	0.033
Jeff to Holland	0.4545	Current	2256	1273.76		10.16	170.76	0.85	0.034
Jeff to Holland	0.4356	Current	2256	1273.9		6.88	332.9	0.53	0.04
Jeff to Holland	0.4167	Current	2256	1273.85		5.73	353.48	0.4	0.04
Jeff to Holland	0.3977	Current	2256	1272.63	1272.63	10.36	255.88	0.78	0.042
Jeff to Holland	0.3864	Current	2256	1272.13	1272.13	10.36	294.22	0.78	0.046
Jeff to Holland	0.3826		Bridge						
Jeff to Holland	0.3788	Current	2256	1272.26	1271.97	6.09	551.88	0.44	0.034
Jeff to Holland	0.3598	Current	2256	1271.7		6.83	411.5	0.6	0.037
Jeff to Holland	0.3409	Current	2256	1271.42		6.67	369.81	0.52	0.038
Jeff to Holland	0.322	Current	2256	1271.15		6.3	319.04	0.5	0.035
Jeff to Holland	0.303	Current	2256	1270.34	1270.34	8.79	268.57	0.76	0.036
Jeff to Holland	0.2841	Current	2256	1270.14		5.47	306.8	0.44	0.037
Jeff to Holland	0.2652	Current	2256	1270.04		4.53	299.3	0.34	0.036
Jeff to Holland	0.2462	Current	2256	1269.86		5.34	583.86	0.39	0.045
Jeff to Holland	0.2273	Current	2256	1269.76		4.59	455.8	0.32	0.042
Jeff to Holland	0.2083	Current	2256	1269.56		5.22	270.78	0.35	0.039
Jeff to Holland	0.1894	Current	2256	1269.54		4.3	332.06	0.28	0.04
Jeff to Holland	0.1705	Current	2256	1269.52		3.47	393.96	0.22	0.039
Jeff to Holland	0.1515	Current	2256	1269.48		3.58	394.52	0.21	0.039
Jeff to Holland	0.1326	Current	2256	1268.96		6.69	359.69	0.48	0.035
Jeff to Holland	0.1259	Current	2256	1269.29	1265.39	2.07	396.76	0.12	0.035
Jeff to Holland	0.1184		Culvert						
Jeff to Holland	0.1165	Current	2548	1265.83	1265.83	13.87	283	1	0.03
Jeff to Holland	0.0947	Current	2548	1265.34		7.92	208.49	0.64	0.033
Jeff to Holland	0.0758	Current	2548	1264.58	1264.58	9.73	232.32	0.85	0.033
Jeff to Holland	0.0568	Current	2548	1264.18		8.07	211.45	0.65	0.033
Jeff to Holland	0.0379	Current	2548	1264.01		7.48	210.48	0.55	0.033
Jeff to Holland	0.019	Current	2548	1262.86		11.2	200.99	0.86	0.032
Jeff to Holland	0	Current	2548	1262.4	1262.4	10.2	180.08	0.81	0.032

Fassnight Creek (9/5/03)

1-Hour Duration

Frequency / Precipitation (in)

Current Conditions	1-yr (1.41)	2-yr (1.77)	5-yr (2.25)	10-yr (2.61)	25-yr (3.08)	50-yr (3.45)	100-yr (3.84)	500-yr (4.69)
Flow into culvert @ Holland Ave. (cfs)	849	1185	1655	2029	2578	3032	**3571**	4962
Flow out of culvert @ Jefferson Ave. (cfs)	888	1243	1740	2136	2715	3198	**3764**	5234
Flow into culvert @ Campbell St. (cfs)	1014	1414	1981	2437	3109	3660	**4313**	5959
Fully Developed Conditions								
Flow into culvert @ Holland Ave. (cfs)	1039	1428	1985	2414	3030	3535	**4103**	5477
Flow out of culvert @ Jefferson Ave. (cfs)	1095	1508	2101	2552	3208	3741	**4350**	5806
Flow into culvert @ Campbell St. (cfs)	1241	1708	2389	2910	3660	4282	**5006**	6676

2-Hour Duration

Frequency / Precipitation (in)

Current Conditions	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	**100-yr**	500-yr
Flow into culvert @ Holland Ave. (cfs)	796	1084	1484	1804	2279	2698	**3200**	4550
Flow out of culvert @ Jefferson Ave. (cfs)	837	1144	1568	1906	2406	2849	**3383**	4823
Flow into culvert @ Campbell St. (cfs)	955	1304	1798	2188	2749	3240	**3833**	5450
Fully Developed Conditions								
Flow into culvert @ Holland Ave. (cfs)	945	1272	1726	2074	2577	2978	**3492**	4812
Flow out of culvert @ Jefferson Ave. (cfs)	1001	1349	1833	2205	2740	3167	**3695**	5100
Flow into culvert @ Campbell St. (cfs)	1146	1551	2113	2546	3164	3665	**4228**	5772

3-Hour Duration

Frequency / Precipitation (in)

Current Conditions	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	**100-yr**	500-yr
Flow into culvert @ Holland Ave. (cfs)	692	940	1274	1542	1931	2366	**2923**	4008
Flow out of culvert @ Jefferson Ave. (cfs)	729	995	1349	1633	2043	2499	**3092**	4256
Flow into culvert @ Campbell St. (cfs)	831	1142	1552	1880	2345	2807	**3474**	4810
Fully Developed Conditions								
Flow into culvert @ Holland Ave. (cfs)	812	1090	1481	1789	2216	2561	**3025**	4199
Flow out of culvert @ Jefferson Ave. (cfs)	862	1158	1574	1901	2357	2721	**3202**	4459
Flow into culvert @ Campbell St. (cfs)	992	1338	1812	2189	2711	3135	**3615**	5043

6-Hour Duration

Frequency / Precipitation (in)

Current Conditions	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	**100-yr**	500-yr
Flow into culvert @ Holland Ave. (cfs)	510	718	977	1198	1512	1784	**2124**	2858
Flow out of culvert @ Jefferson Ave. (cfs)	541	757	1038	1265	1602	1895	**2256**	3040
Flow into culvert @ Campbell St. (cfs)	612	864	1172	1440	1800	2140	**2548**	3441
Fully Developed Conditions								
Flow into culvert @ Holland Ave. (cfs)	606	845	1150	1380	1703	1967	**2275**	3004
Flow out of culvert @ Jefferson Ave. (cfs)	643	894	1219	1464	1804	2083	**2407**	3178
Flow into culvert @ Campbell St. (cfs)	739	1021	1390	1668	2053	2365	**2729**	3602